Global Modeling and Assimilation Office

GMAO Office Note No. 9 (Version 1.0)

MERRA-2: File Specification

Release Date: September 25, 2015

Global Modeling and Assimilation Office
Earth Sciences Division
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771

This page intentionally left blank.

MERRA-2: File Specification

Document maintained by Michael Bosilovich and Rob Lucchesi (GMAO, NASA GSFC)

This document should be cited as
Bosilovich, M. G., R. Lucchesi, and M. Suarez, 2015: MERRA-2: File Specification. GMAO Office Note No. 9 (Version 1.0), 73 pp, available from http://gmao.gsfc.nasa.gov/pubs/office_notes.

Approved by:

________________________9/25/2015___________
Steven Pawson   Date
Chief, Global Modeling and Assimilation Office
Code 610.1, NASA GSFC

REVISION HISTORY

Version Number	Revision Date	Extent of Changes
1.0	9/25/2015	Baseline

Table of Contents

1. INTRODUCTION **1**

2. FORMAT AND FILE ORGANIZATION **3**
2.1 DIMENSIONS 3
2.2 VARIABLES 4
2.3 GLOBAL ATTRIBUTES 5

3. INSTANTANEOUS VERSUS TIME-AVERAGED PRODUCTS **8**

4. GRID STRUCTURE **9**
4.1 HORIZONTAL STRUCTURE 9
4.2 VERTICAL STRUCTURE 9

5. FILE NAMING CONVENTIONS **11**
5.1 FILE NAMES 11
5.2 EARTH SCIENCE DATA TYPES (ESDT) NAME 13

6. MERRA-2 DATA COLLECTIONS **15**
CONSTANTS 15
const_2d_asm_Nx (M2C0NXASM): Constant Model Parameters *15*
INSTANTANEOUS TWO-DIMENSIONAL COLLECTIONS 15
inst1_2d_asm_Nx (M2I1NXASM): Single-Level Diagnostics *15*
inst1_2d_int_Nx (M2I1NXINT): Vertically Integrated Diagnostics *17*
inst1_2d_lfo_Nx (M2I1NXLFO): Land Surface Forcings *17*
inst3_2d_gas_Nx (M2I3NXGAS): Aerosol Optical Depth Analysis *18*
INSTANTANEOUS THREE-DIMENSIONAL COLLECTIONS 18
inst3_3d_aer_Nv (M2I3NVAER): Aerosol Mixing Ratio *18*
inst3_3d_asm_Np (M2I3NPASM): Assimilated Meteorological Fields *19*
inst3_3d_asm_Nv (M2I3NVASM): Assimilated Meteorological Fields *20*
inst3_3d_chm_Nv (M2I3NVCHM): Carbon Monoxide and Ozone Mixing Ratio *21*
inst3_3d_gas_Nv (M2I3NVGAS): Aerosol Mixing Ratio Analysis Increments *21*
inst6_3d_ana_Np (M2I6NPANA): Analyzed Meteorological Fields *22*
inst6_3d_ana_Nv (M2I6NVANA): Analyzed Meteorological Fields *22*
TIME AVERAGED TWO-DIMENSIONAL COLLECTIONS 23
statD_2d_slv_Nx (M2SDNXSLV): Single-Level Diagnostics *23*
tavg1_2d_adg_Nx (M2T1NXADG): Aerosol Diagnostics (extended) *23*
tavg1_2d_aer_Nx (M2T1NXAER): Aerosol Diagnostics *28*
tavg1_2d_chm_Nx (M2T1NXCHM): Carbon Monoxide and Ozone Diagnostics *30*
tavg1_2d_csp_Nx (M2T1NXCSP): COSP Satellite Simulator *30*
tavg1_2d_flx_Nx (M2T1NXFLX): Surface Flux Diagnostics *32*
tavg1_2d_int_Nx (M2T1NXINT): Vertically Integrated Diagnostics *33*
tavg1_2d_lfo_Nx (M2T1NXLFO): Land Surface Forcings *38*
tavg1_2d_lnd_Nx (M2T1NXLND): Land Surface Diagnostics *39*
tavg1_2d_ocn_Nx (M2T1NXOCN): Ocean Surface Diagnostics *41*
tavg1_2d_rad_Nx (M2T1NXRAD): Radiation Diagnostics *42*
tavg1_2d_slv_Nx (M2T1NXSLV): Single-Level Diagnostics *44*
tavg3_2d_glc_Nx (M2T3NXGLC): Land Ice Surface Diagnostics *46*
TIME AVERAGED THREE-DIMENSIONAL COLLECTIONS 46
tavg3_3d_asm_Nv (M2T3NVASM): Assimilated Meteorological Fields *46*

tavg3_3d_cld_Np (M2T3NPCLD): Cloud Diagnostics *47*
tavg3_3d_cld_Nv (M2T3NVCLD): Cloud Diagnostics *48*
tavg3_3d_mst_Ne (M2T3NEMST): Moist Processes Diagnostics *49*
tavg3_3d_mst_Np (M2T3NPMST): Moist Processes Diagnostics *49*
tavg3_3d_mst_Nv (M2T3NVMST): Moist Processes Diagnostics *50*
tavg3_3d_nav_Ne (M2T3NENAV): Vertical Coordinates (Edges) *50*
tavg3_3d_odt_Np (M2T3NPODT): Ozone Tendencies *51*
tavg3_3d_qdt_Np (M2T3NPQDT): Moist Tendencies *51*
tavg3_3d_rad_Np (M2T3NPRAD): Radiation Diagnostics *52*
tavg3_3d_rad_Nv (M2T3NVRAD): Radiation Diagnostics *52*
tavg3_3d_tdt_Np (M2T3NPTDT): Temperature Tendencies *53*
tavg3_3d_trb_Ne (M2T3NETRB): Turbulence Diagnostics *53*
tavg3_3d_trb_Np (M2T3NPTRB): Turbulence Diagnostics *54*
tavg3_3d_udt_Np (M2T3NPUDT): Wind Tendencies *55*
DIGITAL OBJECT IDENTIFIER (DOI) TABLES 56

APPENDIX: BUDGETS 60
ATMOSPHERIC BUDGETS 60
Atmospheric Mass *61*
Atmospheric Water *61*
Atmospheric Kinetic Energy *64*
Virtual Enthalpy *65*
Total Energy *67*
Potential Temperature *68*
Atmospheric Ozone *69*
LAND BUDGETS 69
Total Land Water Budget *69*
Total Land Energy Budget *70*

REFERENCES 72

WEB RESOURCES 73

1. Introduction

The second Modern-Era Retrospective analysis for Research and Applications (MERRA-2) is a NASA atmospheric reanalysis that begins in 1980. It replaces the original MERRA reanalysis (Rienecker et al., 2011) using an upgraded version of the Goddard Earth Observing System Model, Version 5 (GEOS-5) data assimilation system. MERRA-2 includes updates to the model (Molod et al., 2012; 2014) and to the Global Statistical Interpolation (GSI) analysis scheme of Wu et al. (2002). Details of the MERRA-2 system, including the major changes from the MERRA system, are summarized in the companion GMAO Office Note No. 10. The major motivation for replacing MERRA with MERRA-2 is the fact that the MERRA data assimilation system was frozen in 2008 and is not capable of ingesting several important new data types: as the older satellite instruments fail, the number of observations available for assimilation in MERRA is decreasing rapidly. MERRA-2 uses GEOS-5, Version 5.12.4, which is able to use the newer microwave sounders and hyperspectral infrared radiance instruments, as well as other data types.

The file collections described in Section 6 of this document include some important changes from those of the MERRA dataset (Lucchesi, 2012).

Unlike in MERRA, all data collections from MERRA-2 are provided on the same horizontal grid. This grid has 576 points in the longitudinal direction and 361 points in the latitudinal direction, corresponding to a resolution of 0.625°×0.5°. The longitudinal resolution of the data is changed from 0.667° in MERRA and the latitudinal resolution remains unchanged (0.5°). The low-resolution MERRA file collections intended for use by chemistry-transport models have been discontinued in MERRA-2, but the necessary information is retained in the output collections. The version of the GEOS-5 MERRA model used a regular latitude-longitude grid and (most of the) output collections were provided on that grid. While the output collections of MERRA-2 are on the regular 0.625°×0.5° longitude-by-latitude grid, the GEOS-5 model version computed all fields on a cubed-sphere grid with an approximate resolution of 50km×50km. The distributed data collections are spatially interpolated to the latitude-longitude grid, for the convenience of users. There are no changes in the vertical grids used: variables are provided on either the native vertical grid (at 72 model layers or the 73 edges), or interpolated to 42 standard pressure levels. More details on the grid are provided in Section 4.

There is a difference between MERRA and MERRA-2 over land surfaces, where MERRA-2 uses observation-based precipitation data as forcing for the land surface parameterization. This approach is similar to the gauge-based precipitation forcing developed for MERRA-Land (Reichle et al., 2011; Reichle, 2012; Reichle and Liu, 2014). The precipitation forcing data derived from this approach is archived as the output variable called PRECTOTCORR in the MERRA-2 FLX and LFO collections (see Section 6). Note that the forcing precipitation is not purely gauge observations, as it tapers back to MERRA-2 model generated precipitation poleward of 42.5° latitude, and is completely MERRA-2 precipitation poleward of 62.5°. Also, over continental Africa, the observations change to the CMAP gauge-satellite product, due to limitations in the available gauge observations. Care must be taken in mass balance studies as the difference between the observation-based and model-generated precipitation will affect the water budget when land and atmosphere budgets are combined.

Along with the enhanced use of satellite observations in MERRA-2, a secondary motivation was to include more aspects of the Earth System. An important aspect of this is the assimilation of aerosol information, based on the off-line "MERRAero" dataset that was integrated using meteorological fields from MERRA. MERRA-2 aerosol variables are included in additional file collections, which use the tags AER, ADG and GAS in their file names, similarly to the MERRAero data file (da Silva et al., 2015).

Reflecting the broader scope of the assimilation system, there are several other new file collections. MERRA-2 includes a mass balance over glaciated land surfaces, which is written in the GLC collection. Several surface variables have additional daily statistics written in a separate collection called statD. This includes the maximum and minimum daily two-meter temperature, captured at the model time step, between 00:00 UTC and 23:59 UTC every day. The GEOS-5 model also includes the CFMIP Observations Simulator Package (COSP). COSP output for ISCCP and MODIS is provided in the CSP collection.

The MERRA-2 data are available online through the Goddard Earth Sciences (GES) Data and Information Services Center (DISC) (http://disc.sci.gsfc.nasa.gov/mdisc/). Further documentation and information on the data access procedures can be found at http://gmao.gsfc.nasa.gov. Note that each MERRA-2 data collection has a citable DOI, that should be used in peer-reviewed publications (Tables 6.1-6.3).

2. Format and File Organization

MERRA-2 data files are provided in netCDF-4 format, rather than the HDF-5/HDF-EOS format used for MERRA. Since netCDF-4 files are actually HDF-5 files that are structured in a special way, netCDF-4 files can also be read by HDF-5 tools. The data files adhere to the netCDF "classic" data model, which will allow source code used to read older netCDF formats to still work when compiled with the netCDF-4 and HDF-5 libraries. The data products will adhere to the older COARDS metadata conventions and many of the CF metadata conventions, although the files are not fully CF-compliant. The conventions for identifying dimension information are followed, which should allow MERRA-2 files to be used by many tools that are CF-compliant.

Due to the size of the MERRA-2 archive, most product collections are compressed with a GRIB-like method that is invisible to the user. This method does degrade the precision of the data, but every effort has been made to ensure that differences between the product and the original, non-degraded data are not scientifically meaningful. Once the precision has been degraded, the files are written using the standard (internal) Lempel-Ziv deflation available in netCDF-4.

The MERRA-2 data assimilation system runs on a cube sphere grid, but these native data are not distributed. Rather, in post-processing the data, it has been interpolated to the regular latitude-longitude grid discussed in this document. The interpolation includes two options, a conservative remapping (simply a binning routine) and a non-conservative bilinear interpolation. Most variable collections were transformed using the bilinear interpolation. The conservatively remapped file collections are the vertical integrals and aerosol diagnostics, specifically:

tavg1_2d_int_Nx
inst1_2d_int_Nx
tavg1_2d_aer_Nx
tavg1_2d_chm_Nx
inst3_3d_aer_Nv
inst3_3d_chm_Nv
inst3_3d_chm_Np

In some collections, there are duplicate or component variables. For example, net surface longwave radiation is in the time averaged vertical integral collection, while the components are in the 2-D radiation collection. Computing the net surface longwave radiation from the tavg1_2d_rad_Nx files will not precisely equal the net longwave radiation in tavg1_2d_ind_Nx, because of the differences in remapping. As a rule of thumb, only the data that have been conservatively remapped will balance to the highest precision.

2.1 Dimensions

Every MERRA-2 collection contains variables that define the dimensions of longitude, latitude, and time. Product collections that contain three-dimensional data will also have a vertical dimension that defines either pressure levels or the index associated with the model level (see

Section 4.2). Dimension variables have an attribute named "units," set to an appropriate string defined by the CF and COARDS conventions that can be used by applications to identify the dimension.

Table 2.1-1. Dimension Variables Contained in GMAO NetCDF Files

Name	**Description**	**Type**	***units* attribute**
lon	Longitude	double	degrees_east
lat	Latitude	double	degrees_north
lev	pressure or layer index	double	hPa or layer
time	minutes since first time in file	int	minutes

2.2 Variables

Variables are stored as HDF-5 dataset objects, which are analogous to the HDF-4 SDS arrays used for MERRA. MERRA-2 uses the "classic" netCDF data model and does not use any of the extensions supported by netCDF-4 and the underlying HDF-5 format. This allows applications written to read netCDF files to easily read variables without having to modify code. Variable names are listed in the Section 6 along with the number and sizes of dimensions. One can quickly list the variables in the file by using common utilities such as *ncdump,* which is distributed with the netCDF-4 library. With the '-h' flag, this utility will display all information about the file and its contents, including metadata associated with each variable. The variable name is analogous to the *short name* in the MERRA HDF-EOS files. A short description of the variable is provided in the *long_name* and *standard_name* metadata parameters. A glossary with a brief description of each variable is available in the separate GEOS-5 Variable Definition Glossary, available on the GMAO web page

Each variable has several useful metadata attributes. Many of these attributes are required by the CF and COARDS conventions, while others are specific for GMAO products. The following table lists required attributes. Other attributes may be included for internal GMAO use and can be ignored.

Table 2.2-1 Metadata attributes associated with each variable.

Name	**Type**	**Description**
_FillValue	32-bit float	Floating-point value used to identify missing data. Normally set to 1e15. Required by CF.
missing_value	32-bit float	Same as _FillValue. Required for COARDS backwards compatibility.

Name	Type	Description
valid_range	32-bit float, array(2)	This attribute defines the valid range of the variable. The first element is the smallest valid value and the second element is the largest valid value. Required by CF. In MERRA-2 files these are set to -/+ _FillValue.
long_name	String	A brief description of the variable contents taken from the *Description* column of the tables in Section 6.
standard_name	Char String	An ad hoc description of the variable as required by COARDS. It approximates the standard names as defined in an early version of CF conventions, but is not strictly CF-compliant. (Eaton et al., 2011; NOAA, 1995).
units	Char String	The units of the variable. Must be a string that can be recognized by UNIDATA's Udunits package.
scale_factor	32-bit float	If variable is packed as 16-bit integers, this is the scale_factor for expanding to floating-point. Currently data are not packed, thus value is 1.0.
add_offset	32-bit float	If variable is packed as 16-bit integers, this is the offset for expanding to floating-point. Currently, data are not packed, thus value is 0.0.

2.3 Global Attributes

In addition to HDF-5 dataset variables and dimension scales, global metadata is also stored in GMAO netCDF-4 files. Some metadata are required by the CF/COARDS conventions, some are present to meet ECS requirements, and others as a convenience to users of GMAO products. A summary of global attributes present in all MERRA-2 files is shown in Table 2.3-1. All global metadata parameters are of type character

Table 2.3-1 Global metadata attributes associated with each SDS.

Name	Description
History	Production/creation date of this file.
Comment	Internal/original GMAO filename (for provenance).
Filename	Filename of this granule.
Conventions	Identification of the file convention used, currently "$CF^{-1}.0$"

Name	**Description**
Institution	“NASA Global Modeling and Assimilation Office”
References	“http://gmao.gsfc.nasa.gov”
Format	“NetCDF-4/HDF-5”
SpatialCoverage	Global
VersionID	The GEOS-5 version used for MERRA-2, “5.12.4”.
Temporal Range	The beginning and ending dates of the MERRA-2 reanalysis. The ending date is assumed, but may change.
identifier_product_doi_authority	“http://dx.doi.org”
Shortname	Product short name used by G-DISC
RangeBeginningDate	Date corresponding to the first timestep in this file.
RangeBeginningTime	Time corresponding to the first timestep in this file.
RangeEndingDate	Date corresponding to the last timestep in this file.
RangeEndingTime	Time corresponding to the last timestep in this file.
GranuleID	Filename for this product.
ProductionDateTime	Production date & time of this granule.
LongName	Description of product type.
Title	Description of product type.
SouthernmostLatitude	“-90.0”
NorthernmostLatitue	“90.0”
WesternmostLatitude	“-180.0”
EasternmostLatitude	“179.375”
LatitudeResolution	“0.5”
LongitudeResolution	“0.625”

Name	Description
DataResolution	Horizontal and vertical resolution of granule.
identifier_product_doi	Unique Digital Object Identifier
Source	CVS tag associated with GEOS-5 version.
Contact	“http://gmao.gsfc.nasa.gov”

3. Instantaneous versus Time-Averaged Products

Each file collection listed in Section 6 contains either instantaneous or time-averaged products.

All instantaneous collections contain fields at *synoptic times* (00 GMT, 06 GMT, 12 GMT, and 18 GMT). In addition, three-hourly instantaneous collections also include snapshots at *mid-synoptic times* (03 GMT, 09 GMT, 15 GMT, and 21 GMT). 1-hourly instantaneous diagnostics of some states fields and other weather diagnostics are also provided. Monthly means of instantaneous diagnostics have also been computed.

Time-averaged collections contain hourly, three-hourly, monthly, or monthly diurnal means, but not mixtures of these. A new daily mean collection is included to include diagnostics of the near surface maximum and minimum air temperature. Files with daily mean values are also available through the MDISC subsetting tools. Each time-averaged collection consists of a continuous sequence of data averaged over the indicated interval and time stamped with the central time of the interval. For hourly data, for example, these times are 00:30 GMT, 01:30 GMT, 02:30 GMT, etc. Only products consisting exclusively of two-dimensional (horizontal) fields are produced hourly. Three-hourly time-averaged files contain averages over time intervals centered and time stamped at 01:30 GMT, 04:30 GMT, 07:30 GMT, and so on. Monthly files represent averages for the calendar months, accounting for leap years. For monthly means, each file contains a single month.

In MERRA-2, a new collection is included for certain daily statistics computed from the model time step integration. Daily maximum and minimum temperatures are saved from the time step in which they occur and saved as a daily value, alongside the daily mean temperature (all at 2m above the surface).

Each hourly, three-hourly, or six-hourly collection, whether instantaneous or time-averaged, consist of a set of daily files, with the date as part of the filename. For collections of monthly or seasonal means each month or season is in a separate file, and file names also include the year and month in the file name. Monthly means also include certain quadratic information (such as the variance and covariance of certain variables).

4. Grid Structure

4.1 Horizontal Structure

In MERRA-2, all fields are provided on the same 5/8° longitude by ½° latitude grid. The GEOS-5 MERRA-2 ***native grid*** is a cubed sphere. The gridded output is to a global horizontal grid, consisting of **IMn=576** points in the longitudinal direction and **JMn=361** points in the latitudinal direction. The horizontal native grid origin, associated with variables indexed (i=1, j=1) represents a grid point located at (180°W, 90°S). Latitude (φ) and longitude (λ) of grid points as a function of their indices (i, j) can be determined by:

$$\lambda_i = -180 + (\Delta\lambda)_n (i-1), \quad i = 1, \mathrm{IMn}$$

$$\varphi_j = -90 + (\Delta\varphi)_n (j-1), \quad j = 1, \mathrm{JMn}$$

Where $(\Delta\lambda)_n$=5/8° and $(\Delta\varphi)_n$ = 1/2°. For example, (i = 289, j = 181) corresponds to a grid point at (λ = 0, φ = 0).

4.2 Vertical Structure

Gridded products use four different vertical configurations: Horizontal-only (can be vertical integrals, single level, or surface values), pressure-level, model-level, or model-edge. Horizontal-only data for a given variable appear as 3-dimensional fields (x, y, time), while pressure-level, model-level, or model-edge data appear as 4-dimensional fields (x, y, z, time). In all cases the time dimension spans multiple files with one time in each file. Pressure-level data is output on the **LMp=42** pressure levels shown in Table 4.1. The GEOS-5 model layers used for MERRA-2 products are on a terrain-following hybrid sigma-p coordinate. Model-level data will be output on the **LM=72** layers shown in the second table of Table 4.2. The model-edge products contain fields with **LMe = LM + 1** levels representing the layer edges. The pressure at the model top is a fixed constant, **PTOP=0.01 hPa**. As with MERRA, pressures at model edges should be computed by summing the DELP starting at PTOP. A representative pressure for the layer can then be obtained from these. In the GEOS-4 *eta* files, one could compute the pressure on the edges by using the "ak" and "bk" values and the surface pressure. In GEOS-5, the full 3-dimensional pressure variables are explicitly provided through ($DELP_{\mathbf{ijl}}$) and PTOP. For the MERRA-2 products documented here, all model-level fields are on a hybrid-sigma coordinate, and their vertical location could be obtained from the "ak-bk" relationship as well. But this may change in future GMAO systems. We thus recommend that users rely on the reported 3D pressure distribution, and not use those computed from the "ak" and "bk".

Note that the indexing for the GEOS-5 vertical coordinate system in the vertical is top to bottom, i.e., layer 1 is the top layer of the atmosphere, while layer LM is adjacent to the earth's surface. The same is true for edge variables, with level 1 being the top of the model's atmosphere (PTOP), and level LM+1 being the surface. In early versions of certain post processing routines, such as the GES DISC Subsetter, may alter meta data and the direction of the vertical grid. While this has likely been address in the MERRA-2 interface to the data, is prudent to verify the meta data of downloaded or post processed data.

Table 4.1 Pressure-level data will be output on the following 42 pressure levels:

Level	P(hPa)	Level	P(hPa)	Level	P(hPa)	Level	P(hPa)	Level	P(hPa)	Level	P(hPa)
1	1000	8	825	15	600	22	250	29	30	36	2
2	975	9	800	16	550	23	200	30	20	37	1
3	950	10	775	17	500	24	150	31	10	38	0.7
4	925	11	750	18	450	25	100	32	7	39	0.5
5	900	12	725	19	400	26	70	33	5	40	0.4
6	875	13	700	20	350	27	50	34	4	41	0.3
7	850	14	650	21	300	28	40	35	3	42	0.1

Table 4.2 Products on the native vertical grid will be output on the following levels. Pressures are nominal for a 1000 hPa surface pressure and refer to the top edge of the layer. Note that the bottom layer has a nominal thickness of 15 hPa.

Level	P(hPa)	Lev	P(hPa)	Lev	P(hPa)	Lev	P(hPa)	Lev	P(hPa)	Lev	P(hPa)
1	0.0100	13	0.6168	25	9.2929	37	78.5123	49	450.000	61	820.000
2	0.0200	14	0.7951	26	11.2769	38	92.3657	50	487.500	62	835.000
3	0.0327	15	1.0194	27	13.6434	39	108.663	51	525.000	63	850.000
4	0.0476	16	1.3005	28	16.4571	40	127.837	52	562.500	64	865.000
5	0.0660	17	1.6508	29	19.7916	41	150.393	53	600.000	65	880.000
6	0.0893	18	2.0850	30	23.7304	42	176.930	54	637.500	66	895.000
7	0.1197	19	2.6202	31	28.3678	43	208.152	55	675.000	67	910.000
8	0.1595	20	3.2764	32	33.8100	44	244.875	56	700.000	68	925.000
9	0.2113	21	4.0766	33	40.1754	45	288.083	57	725.000	69	940.000
10	0.2785	22	5.0468	34	47.6439	46	337.500	58	750.000	70	955.000
11	0.3650	23	6.2168	35	56.3879	47	375.000	59	775.000	71	970.000
12	0.4758	24	7.6198	36	66.6034	48	412.500	60	800.000	72	985.000

5. File Naming Conventions

The filename of each GEOS-5 product will be stored in the metadata parameter GranuleID.. Each product also has a 9-character "ShortName" which is specified in the metadata and is often called an Earth Science Data Type (ESDT). In MERRA-2 each file collection has a unique ESDT index. The ESDT index convention is described in section 5.2.

5.1 File Names

The standard full name for the assimilated GEOS-5 MERRA-2 products will consist of three dot-delimited nodes:

runid. collection.timestamp

The node fields, which vary from file to file, are defined as follows:

runid

All MERRA-2 *Mainstream* runs are identified by **MERRA2_**SVv , where the numeric qualifiers S and Vv denote the production *Stream* and the *Version* numbers.

MERRA-2 was run in four production *Streams*, each of the first three covering approximately a third of the MERRA-2 period, with the fourth stream starting within a couple years of real time. If the stream number is not applicable (the case for ancillary products, such as forecasts), *S* is set to 0, otherwise it is 1, 2, 3 or 4. Initial conditions for the four MERRA-2 streams were derived from MERRA with a subsequent single year spin-up period, which has not been released in MERRA-2.

The *Version* numbers are non-zero when there is more than one version of the dataset. It is usually zero, denoting the original processing. MERRA-2 was conducted with a frozen assimilation system, so there should be no updates or patches to the GEOS-5 software. Version changes indicate either that a problem was encountered after product release and a reprocessing was necessary (v), or a period was reprocessed with a modified version of the system for scientific studies (V). For any such reprocessing, the version number will be incremented appropriately and this will be documented in the metadata parameter “history.” Information on version differences will also be available at the MERRA-2 web site (available through http://gmao.gsfc.nasa.gov/).

***collection*:**

All MERRA-2 data are organized into file *collections* that contain fields with common characteristics. These collections are used to make the data more accessible for specific purposes. Fields may appear in more than one collection. Collection names are of the form *freq_dims_group_HV*, where the four attributes are:

freq: time-independent (**cnst**), instantaneous (**inst***F*)**,** statistics (**stat***F*) or time-average (**tavg***F*), where *F* indicates the frequency or averaging interval and can be any of the following:

1 = Hourly
3 = 3-Hourly
6 = 6-Hourly
M = Monthly mean
D = Daily Value (mean or other statistic, only used for **stat**)
U = Monthly-Diurnal mean
0 = Not Applicable

A *freq* designation of **M** or **U** can apply to either an **inst** or a **tavg** file depending on whether it is a monthly mean of instantaneous or time-averaged data. As of MERRA-2, the only **D** is **stat**, and vice versa. This was added to incorporate daily statistics to the MERRA-2 output collections.

dims: **2d** for collections with only 2-dimensional fields or **3d** for collections with a mix of 2- and 3-dimensional fields.

group: A three-letter mnemonic for the type of fields in the collection. It is a lowercase version of the group designation used in the ESDT name, as listed in the next section.

HV: Horizontal and Vertical grid.

H can be:

N: Native (5/8 x ½) horizontal resolution

V can be:

x: horizontal-only data (surface, single level, etc.) ; *dims* must be **2D**
p: pressure-level data (see Section 4.2 for levels) ; *dims* must be **3D**
v: model layer centers (see Section 4.2) *dims* must be **3D**
e: model layer edges (see Section 4.2) *dims* must be **3D**

timestamp:

This node defines the date and time associated with the data in the file. It has the form *yyyymmdd* for either instantaneous or time-averaged daily files, *yyyymm* for monthly-mean files.

yyyy - year string (e.g. , "2002")
mm - month string (e.g.., "09" for September)
dd - day of the month string (optional)

EXAMPLE:

MERRA2_300.tavg3_3d_tdt_Np.20020915.nc4

This is an example of a MERRA-2 filename from the original version of the third assimilation stream ("MERRA2_300"). The data are 3-hourly time averages ("tavg3"), three-dimensional ("3d"), temperature tendency products ("tdt"), that have been interpolated to pressure levels ("Np"). The file contains 8 3 hourly averages for 15 September 2002 and is in "nc4" format.

Since different streams were used in the data processing, the change between the original streams occurred after one full year of spin up time. The first file in each data stream is then:

MERRA2_100.*.19800101.nc4
MERRA2_200.*.19920101.nc4
MERRA2_300.*.20010101.nc4
MERRA2_400.*.20110101.nc4

5.2 Earth Science Data Types (ESDT) Name

To accommodate EOSDIS toolkit requirements, all MERRA files are associated with a nine-character ESDT. The ESDT is a short (and rather cryptic) handle for users to access sets of files. In MERRA the ESDT will be used to identify the *Mainstream collections* and consists of a compressed version of the collection name of the form:

M2*TFHVGGG*

where

T: Time Description:

- **I** = Instantaneous
- **T =** Time-averaged
- **C** = Time-independent
- **S** = Statistics

F: Frequency

- **1** = Hourly
- **3** = 3-Hourly
- **6** = 6-Hourly
- **M** = Monthly mean
- **D =** Daily statistics
- **U** = Monthly-Diurnal mean
- **0 =** Not Applicable

H: Horizontal Resolution

N = Native

V: Vertical Location

X = Two-dimensional
P = Pressure
V = model layer center
E = model layer edge

GGG: Group

ANA = direct analysis products
ASM = assimilated state variables (from IAU corrector, see System Document)
AER = aerosol mixing ratio
ADG = aerosol extended diagnostics
TDT = tendencies of temperature
UDT = tendencies of eastward and northward wind components
QDT = tendencies of specific humidity
ODT = tendencies of ozone
GAS = aerosol optical depth
GLC = Land Ice Surface
LND = land surface variables
LFO = land surface forcing output
FLX = surface turbulent fluxes and related quantities
MST = moist processes
CLD = clouds
RAD = radiation
CSP = COSP satellite simulator
TRB = turbulence
SLV = single level
INT = vertical integrals
CHM = chemistry forcing
OCN = ocean
NAV = vertical coordinates

6. MERRA-2 data collections

This section lists the variables in each data collection. More details on the variable definitions may be found in the GEOS-5 Variable Definition Glossary, available at the GMAO web page. In the tables, variable names refer to HDF names, which are uppercase.

Constants

const_2d_asm_Nx (M2C0NXASM): Constant Model Parameters

Frequency: *constant from 03:00 UTC (time-invariant)*

Spatial Grid: *2D, single-level, full horizontal resolution*

Dimensions: *longitude=576, latitude=361, time=1*

Granule Size: *~6 MB*

Name	*Dim*	*Description*	*Units*
AREA	tyx	grid cell area	m^2
FRLAKE	tyx	fraction of lake	1
FRLAND	tyx	fraction of land	1
FRLANDICE	tyx	fraction of land ice	1
FROCEAN	tyx	fraction of ocean	1
PHIS	tyx	surface geopotential height	$m^2 s^{-2}$
SGH	tyx	isotropic stdv of GWD topography	m

Instantaneous Two-Dimensional Collections

inst1_2d_asm_Nx (M2I1NXASM): Single-Level Diagnostics

Frequency: *1-hourly from 00:00 UTC (instantaneous)*

Spatial Grid: *2D, single-level, full horizontal resolution*

Dimensions: *longitude=576, latitude=361, time=24*

Granule Size: *~194 MB*

Name	*Dim*	*Description*	*Units*
DISPH	tyx	zero plane displacement height	m
PS	tyx	surface pressure	Pa
QV10M	tyx	10-meter specific humidity	kg kg^{-1}
QV2M	tyx	2-meter specific humidity	kg kg^{-1}
SLP	tyx	sea level pressure	Pa
T10M	tyx	10-meter air temperature	K
T2M	tyx	2-meter air temperature	K
TO3	tyx	total column ozone	Dobsons
TOX	tyx	total column odd oxygen	kg m^{-2}
TQI	tyx	total precipitable ice water	kg m^{-2}
TQL	tyx	total precipitable liquid water	kg m^{-2}
TQV	tyx	total precipitable water vapor	kg m^{-2}
TROPPB	tyx	tropopause pressure based on blended estimate	Pa
TROPPT	tyx	tropopause pressure based on thermal estimate	Pa
TROPPV	tyx	tropopause pressure based on EPV estimate	Pa
TROPQ	tyx	tropopause specific humidity using blended TROPP estimate	kg kg^{-1}
TROPT	tyx	tropopause temperature using blended TROPP estimate	K
TS	tyx	surface skin temperature	K
U10M	tyx	10-meter eastward wind	m s^{-1}
U2M	tyx	2-meter eastward wind	m s^{-1}
U50M	tyx	eastward wind at 50 meters	m s^{-1}
V10M	tyx	10-meter northward wind	m s^{-1}
V2M	tyx	2-meter northward wind	m s^{-1}
V50M	tyx	northward wind at 50 meters	m s^{-1}

inst1_2d_int_Nx (M2I1NXINT): Vertically Integrated Diagnostics

Frequency: *1-hourly from 00:00 UTC (instantaneous)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=24*
Granule Size: *~100 MB*

Name	*Dim*	*Description*	*Units*
CPT	tyx	vertically integrated enthalpy	J m^{-2}
KE	tyx	vertically integrated kinetic energy	J m^{-2}
MASS	tyx	atmospheric mass	kg m^{-2}
THV	tyx	vertically integrated virtual potential temperature	K
TOX	tyx	total column odd oxygen	kg m^{-2}
TQI	tyx	total precipitable ice water	kg m^{-2}
TQL	tyx	total precipitable liquid water	kg m^{-2}
TQV	tyx	total precipitable water vapor	kg m^{-2}

inst1_2d_lfo_Nx (M2I1NXLFO): Land Surface Forcings

Frequency: *1-hourly from 00:00 UTC (instantaneous)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=24*
Granule Size: *~61 MB*

Name	*Dim*	*Description*	*Units*
HLML	tyx	surface layer height	m
PS	tyx	surface pressure	Pa
QLML	tyx	surface specific humidity	1
SPEEDLML	tyx	surface wind speed	m s^{-1}
TLML	tyx	surface air temperature	K

inst3_2d_gas_Nx (M2I3NXGAS): Aerosol Optical Depth Analysis

Frequency: *3-hourly from 00:00 UTC (instantaneous)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=8*
Granule Size: *~9 MB*

Name	*Dim*	*Description*	*Units*
AODANA	tyx	Aerosol Optical Depth Analysis	1
AODINC	tyx	Aerosol Optical Depth Analysis Increment	1

Instantaneous Three-Dimensional Collections

inst3_3d_aer_Nv (M2I3NVAER): Aerosol Mixing Ratio

Frequency: *3-hourly from 00:00 UTC (instantaneous)*
Spatial Grid: *3D, model-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=72, time=8*
Granule Size: *~4.0 GB*

Name	*Dim*	*Description*	*Units*
AIRDENS	tzyx	air density	kg m^{-3}
BCPHILIC	tzyx	Hydrophilic Black Carbon	kg kg^{-1}
BCPHOBIC	tzyx	Hydrophobic Black Carbon	kg kg^{-1}
DELP	tzyx	pressure thickness	Pa
DMS	tzyx	Dimethylsulphide	kg kg^{-1}
DU001	tzyx	Dust Mixing Ratio (bin 001)	kg kg^{-1}
DU002	tzyx	Dust Mixing Ratio (bin 002)	kg kg^{-1}
DU003	tzyx	Dust Mixing Ratio (bin 003)	kg kg^{-1}
DU004	tzyx	Dust Mixing Ratio (bin 004)	kg kg^{-1}

DU005	tzyx	Dust Mixing Ratio (bin 005)	kg kg^{-1}
LWI	tyx	land(1) water(0) ice(2) flag	1
MSA	tzyx	Methanesulphonic acid	kg kg^{-1}
OCPHILIC	tzyx	Hydrophilic Organic Carbon (Particulate Matter)	kg kg^{-1}
OCPHOBIC	tzyx	Hydrophobic Organic Carbon (Particulate Matter)	kg kg^{-1}
PS	tyx	surface pressure	Pa
RH	tzyx	relative humidity after moist	1
SO2	tzyx	Sulphur dioxide	kg kg^{-1}
SO4	tzyx	Sulphate aerosol	kg kg^{-1}
SS001	tzyx	Sea Salt Mixing Ratio (bin 001)	kg kg^{-1}
SS002	tzyx	Sea Salt Mixing Ratio (bin 002)	kg kg^{-1}
SS003	tzyx	Sea Salt Mixing Ratio (bin 003)	kg kg^{-1}
SS004	tzyx	Sea Salt Mixing Ratio (bin 004)	kg kg^{-1}
SS005	tzyx	Sea Salt Mixing Ratio (bin 005)	kg kg^{-1}

inst3_3d_asm_Np (M2I3NPASM): Assimilated Meteorological Fields

Frequency: *3-hourly from 00:00 UTC (instantaneous)*
Spatial Grid: *3D, pressure-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=42, time=8*
Granule Size: *~1.1 GB*

Name	*Dim*	*Description*	*Units*
EPV	tzyx	ertels potential vorticity	K m^2 kg^{-1} s^{-1}
H	tzyx	edge heights	m
O3	tzyx	ozone mass mixing ratio	kg kg^{-1}
OMEGA	tzyx	vertical pressure velocity	Pa s^{-1}
PHIS	tyx	surface geopotential height	m^2 s^{-2}
PS	tyx	surface pressure	Pa

QI	tzyx	mass fraction of cloud ice water	kg kg^{-1}
QL	tzyx	mass fraction of cloud liquid water	kg kg^{-1}
QV	tzyx	specific humidity	kg kg^{-1}
RH	tzyx	relative humidity after moist	1
SLP	tyx	sea level pressure	Pa
T	tzyx	air temperature	K
U	tzyx	eastward wind	m s^{-1}
V	tzyx	northward wind	m s^{-1}

inst3_3d_asm_Nv (M2I3NVASM): Assimilated Meteorological Fields

Frequency: *3-hourly from 00:00 UTC (instantaneous)*
Spatial Grid: *3D, model-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=72, time=8*
Granule Size: *~2.1 GB*

Name	*Dim*	*Description*	*Units*
CLOUD	tzyx	cloud fraction for radiation	1
DELP	tzyx	pressure thickness	Pa
EPV	tzyx	ertels potential vorticity	K m^2 kg^{-1} s^{-1}
H	tzyx	mid layer heights	m
O3	tzyx	ozone mass mixing ratio	kg kg^{-1}
OMEGA	tzyx	vertical pressure velocity	Pa s^{-1}
PHIS	tyx	surface geopotential height	m^2 s^{-2}
PL	tzyx	mid level pressure	Pa
PS	tyx	surface pressure	Pa
QI	tzyx	mass fraction of cloud ice water	kg kg^{-1}
QL	tzyx	mass fraction of cloud liquid water	kg kg^{-1}
QV	tzyx	specific humidity	kg kg^{-1}

RH	tzyx	relative humidity after moist	1
SLP	tyx	sea level pressure	Pa
T	tzyx	air temperature	K
U	tzyx	eastward wind	m s^{-1}
V	tzyx	northward wind	m s^{-1}

inst3_3d_chm_Nv (M2I3NVCHM): Carbon Monoxide and Ozone Mixing Ratio

Frequency: *3-hourly from 00:00 UTC (instantaneous)*
Spatial Grid: *3D, model-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=72, time=8*
Granule Size: *~532 MB*

Name	*Dim*	*Description*	*Units*
AIRDENS	tzyx	air density	kg m^{-3}
CO	tzyx	Carbon Monoxide (All Sources)	mol mol^{-1}
DELP	tzyx	pressure thickness	Pa
O3	tzyx	ozone mass mixing ratio	kg kg^{-1}
PS	tyx	surface pressure	Pa

inst3_3d_gas_Nv (M2I3NVGAS): Aerosol Mixing Ratio Analysis Increments

Frequency: *3-hourly from 00:00 UTC (instantaneous)*
Spatial Grid: *3D, model-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=72, time=8*
Granule Size: *~402 MB*

Name	*Dim*	*Description*	*Units*
AIRDENS	tzyx	air density	kg m^{-3}

BCINC	tzyx	Black Carbon Mixing Ratio Analysis Increments	kg kg^{-1}
DUINC	tzyx	Dust Mixing Ratio Analysis Increments	kg kg^{-1}
OCINC	tzyx	Organic Carbon Mixing Ratio Analysis Increments	kg kg^{-1}
SSINC	tzyx	Sea-salt Mixing Ratio Analysis Increments	kg kg^{-1}
SUINC	tzyx	Sulfate Mixing Ratio Analysis Increments	kg kg^{-1}
DELP	tzyx	pressure thickness	Pa

inst6_3d_ana_Np (M2I6NPANA): Analyzed Meteorological Fields

Frequency: *6-hourly from 00:00 UTC (instantaneous)*
Spatial Grid: *3D, pressure-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=42, time=4*
Granule Size: *~509 MB*

Name	***Dim***	***Description***	***Units***
H	tzyx	Geopotential height	m
O3	tzyx	Ozone mixing ratio	kg kg^{-1}
PS	tyx	Surface pressure	Pa
QV	tzyx	Specific humidity	kg kg^{-1}
SLP	tyx	Sea-level pressure	Pa
T	tzyx	Air temperature	K
U	tzyx	Eastward wind component	m/s
V	tzyx	Northward wind component	m/s

inst6_3d_ana_Nv (M2I6NVANA): Analyzed Meteorological Fields

Frequency: *6-hourly from 00:00 UTC (instantaneous)*
Spatial Grid: *3D, model-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=72, time=4*

Granule Size: *~831 MB*

Name	*Dim*	*Description*	*Units*
DELP	tzyx	Layer pressure thickness	Pa
O3	tzyx	Ozone mixing ratio	kg kg^{-1}
PS	tyx	Surface pressure	Pa
QV	tzyx	Specific humidity	kg kg^{-1}
T	tzyx	Air temperature	K
U	tzyx	Eastward wind component	m/s
V	tzyx	Northward wind component	m/s

Time Averaged Two-Dimensional Collections

statD_2d_slv_Nx (M2SDNXSLV): Single-Level Diagnostics

Frequency: *daily from 00:30 UTC (aggregated statistics)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=1*
Granule Size: *~2 MB*

Name	*Dim*	*Description*	*Units*
HOURNORAIN	tyx	time-during an hour with no precipitation	s
T2MMAX	tyx	2-meter air temperature	K
T2MMEAN	tyx	2-meter air temperature	K
T2MMIN	tyx	2-meter air temperature	K
TPRECMAX	tyx	Maximum precipitation rate during the period	kg m^{-2} s^{-1}

tavg1_2d_adg_Nx (M2T1NXADG): Aerosol Diagnostics (extended)

Frequency: *1-hourly from 00:30 UTC (time-averaged)*
Spatial Grid: *2D, single-level, full horizontal resolution*

Dimensions: *longitude=576, latitude=361, time=24*
Granule Size: *~779 MB*

Name	***Dim***	***Description***	***Units***
BCDP001	tyx	Black Carbon Dry Deposition Bin 001	kg m^{-2} s^{-1}
BCDP002	tyx	Black Carbon Dry Deposition Bin 002	kg m^{-2} s^{-1}
BCEM001	tyx	Black Carbon Emission Bin 001	kg m^{-2} s^{-1}
BCEM002	tyx	Black Carbon Emission Bin 002	kg m^{-2} s^{-1}
BCEMAN	tyx	Black Carbon Anthropogenic Emissions	kg m^{-2} s^{-1}
BCEMBB	tyx	Black Carbon Biomass Burning Emissions	kg m^{-2} s^{-1}
BCEMBF	tyx	Black Carbon Biofuel Emissions	kg m^{-2} s^{-1}
BCHYPHIL	tyx	Black Carbon Hydrophobic to Hydrophilic	kg m^{-2} s^{-1}
BCSD001	tyx	Black Carbon Sedimentation Bin 001	kg m^{-2} s^{-1}
BCSD002	tyx	Black Carbon Sedimentation Bin 002	kg m^{-2} s^{-1}
BCSV001	tyx	Black Carbon Convective Scavenging Bin 001	kg m^{-2} s^{-1}
BCSV002	tyx	Black Carbon Convective Scavenging Bin 002	kg m^{-2} s^{-1}
BCWT001	tyx	Black Carbon Wet Deposition Bin 001	kg m^{-2} s^{-1}
BCWT002	tyx	Black Carbon Wet Deposition Bin 002	kg m^{-2} s^{-1}
DUAERIDX	tyx	Dust TOMS UV Aerosol Index	1
DUDP001	tyx	Dust Dry Deposition Bin 001	kg m^{-2} s^{-1}
DUDP002	tyx	Dust Dry Deposition Bin 002	kg m^{-2} s^{-1}
DUDP003	tyx	Dust Dry Deposition Bin 003	kg m^{-2} s^{-1}
DUDP004	tyx	Dust Dry Deposition Bin 004	kg m^{-2} s^{-1}
DUDP005	tyx	Dust Dry Deposition Bin 005	kg m^{-2} s^{-1}
DUEM001	tyx	Dust Emission Bin 001	kg m^{-2} s^{-1}
DUEM002	tyx	Dust Emission Bin 002	kg m^{-2} s^{-1}
DUEM003	tyx	Dust Emission Bin 003	kg m^{-2} s^{-1}
DUEM004	tyx	Dust Emission Bin 004	kg m^{-2} s^{-1}
DUEM005	tyx	Dust Emission Bin 005	kg m^{-2} s^{-1}

DUEXTTFM	tyx	Dust Extinction AOT [550 nm] - PM 1.0 um	1
DUSCATFM	tyx	Dust Scattering AOT [550 nm] - PM 1.0 um	1
DUSD001	tyx	Dust Sedimentation Bin 001	kg m^{-2} s^{-1}
DUSD002	tyx	Dust Sedimentation Bin 002	kg m^{-2} s^{-1}
DUSD003	tyx	Dust Sedimentation Bin 003	kg m^{-2} s^{-1}
DUSD004	tyx	Dust Sedimentation Bin 004	kg m^{-2} s^{-1}
DUSD005	tyx	Dust Sedimentation Bin 005	kg m^{-2} s^{-1}
DUSV001	tyx	Dust Convective Scavenging Bin 001	kg m^{-2} s^{-1}
DUSV002	tyx	Dust Convective Scavenging Bin 002	kg m^{-2} s^{-1}
DUSV003	tyx	Dust Convective Scavenging Bin 003	kg m^{-2} s^{-1}
DUSV004	tyx	Dust Convective Scavenging Bin 004	kg m^{-2} s^{-1}
DUSV005	tyx	Dust Convective Scavenging Bin 005	kg m^{-2} s^{-1}
DUWT001	tyx	Dust Wet Deposition Bin 001	kg m^{-2} s^{-1}
DUWT002	tyx	Dust Wet Deposition Bin 002	kg m^{-2} s^{-1}
DUWT003	tyx	Dust Wet Deposition Bin 003	kg m^{-2} s^{-1}
DUWT004	tyx	Dust Wet Deposition Bin 004	kg m^{-2} s^{-1}
DUWT005	tyx	Dust Wet Deposition Bin 005	kg m^{-2} s^{-1}
OCDP001	tyx	Organic Carbon Dry Deposition Bin 001	kg m^{-2} s^{-1}
OCDP002	tyx	Organic Carbon Dry Deposition Bin 002	kg m^{-2} s^{-1}
OCEM001	tyx	Organic Carbon Emission Bin 001	kg m^{-2} s^{-1}
OCEM002	tyx	Organic Carbon Emission Bin 002	kg m^{-2} s^{-1}
OCEMAN	tyx	Organic Carbon Anthropogenic Emissions	kg m^{-2} s^{-1}
OCEMBB	tyx	Organic Carbon Biomass Burning Emissions	kg m^{-2} s^{-1}
OCEMBF	tyx	Organic Carbon Biofuel Emissions	kg m^{-2} s^{-1}
OCEMBG	tyx	Organic Carbon Biogenic Emissions	kg m^{-2} s^{-1}
OCHYPHIL	tyx	Organic Carbon Hydrophobic to Hydrophilic	kg m^{-2} s^{-1}
OCSD001	tyx	Organic Carbon Sedimentation Bin 001	kg m^{-2} s^{-1}
OCSD002	tyx	Organic Carbon Sedimentation Bin 002	kg m^{-2} s^{-1}

OCSV001	tyx	Organic Carbon Convective Scavenging Bin 001	kg m^{-2} s^{-1}
OCSV002	tyx	Organic Carbon Convective Scavenging Bin 002	kg m^{-2} s^{-1}
OCWT001	tyx	Organic Carbon Wet Deposition Bin 001	kg m^{-2} s^{-1}
OCWT002	tyx	Organic Carbon Wet Deposition Bin 002	kg m^{-2} s^{-1}
SO2EMAN	tyx	SO2 Anthropogenic Emissions	kg m^{-2} s^{-1}
SO2EMBB	tyx	SO2 Biomass Burning Emissions	kg m^{-2} s^{-1}
SO2EMVE	tyx	SO2 Volcanic (explosive) Emissions	kg m^{-2} s^{-1}
SO2EMVN	tyx	SO2 Volcanic (non-explosive) Emissions	kg m^{-2} s^{-1}
SO4EMAN	tyx	SO4 Anthropogenic Emissions	kg m^{-2} s^{-1}
SSAERIDX	tyx	Sea Salt TOMS UV Aerosol Index	1
SSDP001	tyx	Sea Salt Dry Deposition Bin 001	kg m^{-2} s^{-1}
SSDP002	tyx	Sea Salt Dry Deposition Bin 002	kg m^{-2} s^{-1}
SSDP003	tyx	Sea Salt Dry Deposition Bin 003	kg m^{-2} s^{-1}
SSDP004	tyx	Sea Salt Dry Deposition Bin 004	kg m^{-2} s^{-1}
SSDP005	tyx	Sea Salt Dry Deposition Bin 005	kg m^{-2} s^{-1}
SSEM001	tyx	Sea Salt Emission Bin 001	kg m^{-2} s^{-1}
SSEM002	tyx	Sea Salt Emission Bin 002	kg m^{-2} s^{-1}
SSEM003	tyx	Sea Salt Emission Bin 003	kg m^{-2} s^{-1}
SSEM004	tyx	Sea Salt Emission Bin 004	kg m^{-2} s^{-1}
SSEM005	tyx	Sea Salt Emission Bin 005	kg m^{-2} s^{-1}
SSEXTTFM	tyx	Sea Salt Extinction AOT [550 nm] - PM 1.0 um	1
SSSCATFM	tyx	Sea Salt Scattering AOT [550 nm] - PM 1.0 um	1
SSSD001	tyx	Sea Salt Sedimentation Bin 001	kg m^{-2} s^{-1}
SSSD002	tyx	Sea Salt Sedimentation Bin 002	kg m^{-2} s^{-1}
SSSD003	tyx	Sea Salt Sedimentation Bin 003	kg m^{-2} s^{-1}
SSSD004	tyx	Sea Salt Sedimentation Bin 004	kg m^{-2} s^{-1}
SSSD005	tyx	Sea Salt Sedimentation Bin 005	kg m^{-2} s^{-1}
SSSV001	tyx	Sea Salt Convective Scavenging Bin 001	kg m^{-2} s^{-1}

SSSV002	tyx	Sea Salt Convective Scavenging Bin 002	kg m^{-2} s^{-1}
SSSV003	tyx	Sea Salt Convective Scavenging Bin 003	kg m^{-2} s^{-1}
SSSV004	tyx	Sea Salt Convective Scavenging Bin 004	kg m^{-2} s^{-1}
SSSV005	tyx	Sea Salt Convective Scavenging Bin 005	kg m^{-2} s^{-1}
SSWT001	tyx	Sea Salt Wet Deposition Bin 001	kg m^{-2} s^{-1}
SSWT002	tyx	Sea Salt Wet Deposition Bin 002	kg m^{-2} s^{-1}
SSWT003	tyx	Sea Salt Wet Deposition Bin 003	kg m^{-2} s^{-1}
SSWT004	tyx	Sea Salt Wet Deposition Bin 004	kg m^{-2} s^{-1}
SSWT005	tyx	Sea Salt Wet Deposition Bin 005	kg m^{-2} s^{-1}
SUDP001	tyx	Sulfate Dry Deposition Bin 001	kg m^{-2} s^{-1}
SUDP002	tyx	Sulfate Dry Deposition Bin 002	kg m^{-2} s^{-1}
SUDP003	tyx	Sulfate Dry Deposition Bin 003	kg m^{-2} s^{-1}
SUDP004	tyx	Sulfate Dry Deposition Bin 004	kg m^{-2} s^{-1}
SUEM001	tyx	Sulfate Emission Bin 001	kg m^{-2} s^{-1}
SUEM002	tyx	Sulfate Emission Bin 002	kg m^{-2} s^{-1}
SUEM003	tyx	Sulfate Emission Bin 003	kg m^{-2} s^{-1}
SUEM004	tyx	Sulfate Emission Bin 004	kg m^{-2} s^{-1}
SUPMSA	tyx	MSA Prod from DMS Oxidation [column]	kg m^{-2} s^{-1}
SUPSO2	tyx	SO2 Prod from DMS Oxidation [column]	kg m^{-2} s^{-1}
SUPSO4AQ	tyx	SO4 Prod from Aqueous SO2 Oxidation [column]	kg m^{-2} s^{-1}
SUPSO4G	tyx	SO4 Prod from Gaseous SO2 Oxidation [column]	kg m^{-2} s^{-1}
SUPSO4WT	tyx	SO4 Prod from Aqueous SO2 Oxidation (wet dep) [column]	kg m^{-2} s^{-1}
SUSD001	tyx	Sulfate Settling Bin 001	kg m^{-2} s^{-1}
SUSD002	tyx	Sulfate Settling Bin 002	kg m^{-2} s^{-1}
SUSD003	tyx	Sulfate Settling Bin 003	kg m^{-2} s^{-1}
SUSD004	tyx	Sulfate Settling Bin 004	kg m^{-2} s^{-1}
SUSV001	tyx	Sulfate Convective Scavenging Bin 001	kg m^{-2} s^{-1}

SUSV002	tyx	Sulfate Convective Scavenging Bin 002	kg m^{-2} s^{-1}
SUSV003	tyx	Sulfate Convective Scavenging Bin 003	kg m^{-2} s^{-1}
SUSV004	tyx	Sulfate Convective Scavenging Bin 004	kg m^{-2} s^{-1}
SUWT001	tyx	Sulfate Wet Deposition Bin 001	kg m^{-2} s^{-1}
SUWT002	tyx	Sulfate Wet Deposition Bin 002	kg m^{-2} s^{-1}
SUWT003	tyx	Sulfate Wet Deposition Bin 003	kg m^{-2} s^{-1}
SUWT004	tyx	Sulfate Wet Deposition Bin 004	kg m^{-2} s^{-1}

tavg1_2d_aer_Nx (M2T1NXAER): Aerosol Diagnostics

Frequency: *1-hourly from 00:30 UTC (time-averaged)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=24*
Granule Size: *~476 MB*

Name	*Dim*	*Description*	*Units*
BCANGSTR	tyx	Black Carbon Angstrom parameter [470-870 nm]	1
BCCMASS	tyx	Black Carbon Column Mass Density	kg m^{-2}
BCEXTTAU	tyx	Black Carbon Extinction AOT [550 nm]	1
BCFLUXU	tyx	Black Carbon column u-wind mass flux	kg m^{-1} s^{-1}
BCFLUXV	tyx	Black Carbon column v-wind mass flux	kg m^{-1} s^{-1}
BCSCATAU	tyx	Black Carbon Scattering AOT [550 nm]	1
BCSMASS	tyx	Black Carbon Surface Mass Concentration	kg m^{-3}
DMSCMASS	tyx	DMS Column Mass Density	kg m^{-2}
DMSSMASS	tyx	DMS Surface Mass Concentration	kg m^{-3}
DUANGSTR	tyx	Dust Angstrom parameter [470-870 nm]	1
DUCMASS	tyx	Dust Column Mass Density	kg m^{-2}
DUCMASS25	tyx	Dust Column Mass Density - PM 2.5	kg m^{-2}
DUEXTT25	tyx	Dust Extinction AOT [550 nm] - PM 2.5	1

DUEXTTAU	tyx	Dust Extinction AOT [550 nm]	1
DUFLUXU	tyx	Dust column u-wind mass flux	kg m^{-1} s^{-1}
DUFLUXV	tyx	Dust column v-wind mass flux	kg m^{-1} s^{-1}
DUSCAT25	tyx	Dust Scattering AOT [550 nm] - PM 2.5	1
DUSCATAU	tyx	Dust Scattering AOT [550 nm]	1
DUSMASS	tyx	Dust Surface Mass Concentration	kg m^{-3}
DUSMASS25	tyx	Dust Surface Mass Concentration - PM 2.5	kg m^{-3}
OCANGSTR	tyx	Organic Carbon Angstrom parameter [470-870 nm]	1
OCCMASS	tyx	Organic Carbon Column Mass Density	kg m^{-2}
OCEXTTAU	tyx	Organic Carbon Extinction AOT [550 nm]	1
OCFLUXU	tyx	Organic Carbon column u-wind mass flux	kg m^{-1} s^{-1}
OCFLUXV	tyx	Organic Carbon column v-wind mass flux	kg m^{-1} s^{-1}
OCSCATAU	tyx	Organic Carbon Scattering AOT [550 nm]	1
OCSMASS	tyx	Organic Carbon Surface Mass Concentration	kg m^{-3}
SO2CMASS	tyx	SO2 Column Mass Density	kg m^{-2}
SO2SMASS	tyx	SO2 Surface Mass Concentration	kg m^{-3}
SO4CMASS	tyx	SO4 Column Mass Density	kg m^{-2}
SO4SMASS	tyx	SO4 Surface Mass Concentration	kg m^{-3}
SSANGSTR	tyx	Sea Salt Angstrom parameter [470-870 nm]	1
SSCMASS	tyx	Sea Salt Column Mass Density	kg m^{-2}
SSCMASS25	tyx	Sea Salt Column Mass Density - PM 2.5	kg m^{-2}
SSEXTT25	tyx	Sea Salt Extinction AOT [550 nm] - PM 2.5	1
SSEXTTAU	tyx	Sea Salt Extinction AOT [550 nm]	1
SSFLUXU	tyx	Sea Salt column u-wind mass flux	kg m^{-1} s^{-1}
SSFLUXV	tyx	Sea Salt column v-wind mass flux	kg m^{-1} s^{-1}
SSSCAT25	tyx	Sea Salt Scattering AOT [550 nm] - PM 2.5	1
SSSCATAU	tyx	Sea Salt Scattering AOT [550 nm]	1
SSSMASS	tyx	Sea Salt Surface Mass Concentration	kg m^{-3}

SSSMASS25	tyx	Sea Salt Surface Mass Concentration - PM 2.5	kg m^{-3}
SUANGSTR	tyx	SO4 Angstrom parameter [470-870 nm]	1
SUEXTTAU	tyx	SO4 Extinction AOT [550 nm]	1
SUFLUXU	tyx	SO4 column u-wind mass flux	kg m^{-1} s^{-1}
SUFLUXV	tyx	SO4 column v-wind mass flux	kg m^{-1} s^{-1}
SUSCATAU	tyx	SO4 Scattering AOT [550 nm]	1
TOTANGSTR	tyx	Total Aerosol Angstrom parameter [470-870 nm]	1
TOTEXTTAU	tyx	Total Aerosol Extinction AOT [550 nm]	1
TOTSCATAU	tyx	Total Aerosol Scattering AOT [550 nm]	1

tavg1_2d_chm_Nx (M2T1NXCHM): Carbon Monoxide and Ozone Diagnostics

Frequency: *1-hourly from 00:30 UTC (time-averaged)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=24*
Granule Size: *~45 MB*

Name	*Dim*	*Description*	*Units*
COCL	tyx	CO Column Burden	kg m^{-2}
COEM	tyx	CO Emission	kg m^{-2} s^{-1}
COLS	tyx	CO Chemical Loss	kg m^{-2} s^{-1}
COPD	tyx	CO Chemical Production	kg m^{-2} s^{-1}
COSC	tyx	CO Surface Concentration in ppbv	$1e^{-9}$
LWI	tyx	land(1) water(0) ice(2) flag	1
TO3	tyx	total column ozone	Dobsons

tavg1_2d_csp_Nx (M2T1NXCSP): COSP Satellite Simulator

Frequency: *1-hourly from 00:30 UTC (time-averaged)*

Spatial Grid: *2D, single-level, full horizontal resolution*

Dimensions: *longitude=576, latitude=361, time=24*

Granule Size: *~123 MB*

Name	*Dim*	*Description*	*Units*[*]
ISCCPALB	tyx	isccp cloud albedo	1
ISCCPCLDFRC	tyx	isccp total cloud area fraction	1
MDSCLDFRCH2O	tyx	modis cloud fraction water mean	1
MDSCLDFRCHI	tyx	modis cloud fraction high mean	1
MDSCLDFRCICE	tyx	modis cloud fraction ice mean	1
MDSCLDFRCLO	tyx	modis cloud fraction low mean	1
MDSCLDFRCMID	tyx	modis cloud fraction mid mean	1
MDSCLDFRCTTL	tyx	modis cloud fraction total mean	1
MDSCLDSZH20	tyx	modis cloud particle size water mean	m
MDSCLDSZICE	tyx	modis cloud particle size ice mean	m
MDSCLDTOPPS	tyx	modis cloud top pressure total mean	Pa
MDSH2OPATH	tyx	modis liquid water path mean	Kg m^{-2}
MDSICEPATH	tyx	modis ice water path mean	Kg m^{-2}
MDSOPTHCKH2O	tyx	modis optical thickness water mean	1
MDSOPTHCKH2OLG	tyx	modis optical thickness water logmean	1
MDSOPTHCKICE	tyx	modis optical thickness ice mean	1
MDSOPTHCKICELG	tyx	modis optical thickness ice logmean	1
MDSOPTHCKTTL	tyx	modis optical thickness total mean	1
MDSOPTHCKTTLLG	tyx	modis optical thickness total logmean	1

[*] All units in the first version of MERRA-2 COSP output were incorrectly listed as non-dimensional in the data file's metadata. This table includes corrected Units.

tavg1_2d_flx_Nx (M2T1NXFLX): Surface Flux Diagnostics

Frequency: *1-hourly from 00:30 UTC (time-averaged)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=24*
Granule Size: *~379 MB*

Name	*Dim*	*Description*	*Units*
BSTAR	tyx	surface bouyancy scale	m s-2
CDH	tyx	surface exchange coefficient for heat	kg m^{-2} s^{-1}
CDM	tyx	surface exchange coefficient for momentum	kg m^{-2} s^{-1}
CDQ	tyx	surface exchange coefficient for moisture	kg m^{-2} s^{-1}
CN	tyx	surface neutral drag coefficient	1
DISPH	tyx	zero plane displacement height	m
EFLUX	tyx	total latent energy flux	W m^{-2}
EVAP	tyx	evaporation from turbulence	kg m^{-2} s^{-1}
FRCAN	tyx	areal fraction of anvil showers	1
FRCCN	tyx	areal fraction of convective showers	1
FRCLS	tyx	areal fraction of nonanvil large scale showers	1
FRSEAICE	tyx	ice covered fraction of tile	1
GHTSKIN	tyx	Ground heating for skin temp	W m^{-2}
HFLUX	tyx	sensible heat flux from turbulence	W m^{-2}
HLML	tyx	surface layer height	m
NIRDF	tyx	surface downwelling nearinfrared diffuse flux	W m^{-2}
NIRDR	tyx	surface downwelling nearinfrared beam flux	W m^{-2}
PBLH	tyx	planetary boundary layer height	m
PGENTOT	tyx	Total column production of precipitation	kg m^{-2} s^{-1}
PRECANV	tyx	anvil precipitation	kg m^{-2} s^{-1}
PRECCON	tyx	convective precipitation	kg m^{-2} s^{-1}

PRECLSC	tyx	nonanvil large scale precipitation	kg m^{-2} s^{-1}
PRECSNO	tyx	snowfall	kg m^{-2} s^{-1}
PRECTOT	tyx	total precipitation from atm model physics	kg m^{-2} s^{-1}
PRECTOTCORR	tyx	Bias corrected total precipitation	kg m^{-2} s^{-1}
PREVTOT	tyx	Total column re-evap/subl of precipitation	kg m^{-2} s^{-1}
QLML	tyx	surface specific humidity	1
QSH	tyx	effective surface specific humidity	kg kg^{-1}
QSTAR	tyx	surface moisture scale	kg kg^{-1}
RHOA	tyx	air density at surface	kg m^{-3}
RISFC	tyx	surface bulk richardson number	1
SPEED	tyx	surface wind speed	m s^{-1}
SPEEDMAX	tyx	surface wind speed	m s^{-1}
TAUGWX	tyx	surface eastward gravity wave stress	N m^{-2}
TAUGWY	tyx	surface northward gravity wave stress	N m^{-2}
TAUX	tyx	eastward surface stress	N m^{-2}
TAUY	tyx	northward surface stress	N m^{-2}
TCZPBL	tyx	transcom planetary boundary layer height	m
TLML	tyx	surface air temperature	K
TSH	tyx	effective surface skin temperature	K
TSTAR	tyx	surface temperature scale	K
ULML	tyx	surface eastward wind	m s^{-1}
USTAR	tyx	surface velocity scale	m s^{-1}
VLML	tyx	surface northward wind	m s^{-1}
Z0H	tyx	surface roughness for heat	m
Z0M	tyx	surface roughness	m

tavg1_2d_int_Nx (M2T1NXINT): Vertically Integrated Diagnostics

Frequency: *1-hourly from 00:30 UTC (time-averaged)*

Spatial Grid: *2D, single-level, full horizontal resolution*

Dimensions: *longitude=576, latitude=361, time=24*

Granule Size: *~1.3 GB*

Name	*Dim*	*Description*	*Units*
AUTCNVRN	tyx	autoconversion loss of cloud water	kg m^{-2} s^{-1}
BKGERR	tyx	vertically integrated kinetic energy residual for BKG energy conservation	W m^{-2}
COLCNVRN	tyx	accretion loss of cloud water to rain	kg m^{-2} s^{-1}
COLCNVSN	tyx	accretion loss of cloud water to snow	kg m^{-2} s^{-1}
CUCNVCI	tyx	convective source of cloud ice	kg m^{-2} s^{-1}
CUCNVCL	tyx	convective source of cloud water	kg m^{-2} s^{-1}
CUCNVRN	tyx	convective production of rain water	kg m^{-2} s^{-1}
DHDT_ANA	tyx	total potential energy tendency due to analysis	W m^{-2}
DHDT_BKG	tyx	vertically integrated potential energy tendency due to gravity wave background	W m^{-2}
DHDT_CUF	tyx	vertically integrated potential energy tendency due to cumulus friction	W m^{-2}
DHDT_DYN	tyx	vertically integrated potential energy tendency due to dynamics	W m^{-2}
DHDT_FRI	tyx	vertically integrated potential energy tendency due to friction	W m^{-2}
DHDT_GWD	tyx	vertically integrated potential energy tendency across gwd	W m^{-2}
DHDT_MST	tyx	vertically integrated potential energy tendency across moist	W m^{-2}
DHDT_ORO	tyx	vertically integrated potential energy tendency due to orographic gravity waves	W m^{-2}
DHDT_PHY	tyx	total potential energy tendency due to physics	W m^{-2}
DHDT_RAD	tyx	vertically integrated potential energy tendency across radiation	W m^{-2}
DHDT_RAY	tyx	vertically integrated potential energy tendency due to Rayleigh friction	W m^{-2}

DHDT_RES	tyx	vertically integrated cpt tendency residual	W m^{-2}
DHDT_TRB	tyx	vertically integrated potential energy tendency across turbulence	W m^{-2}
DKDT_ANA	tyx	total kinetic energy tendency due to analysis	W m^{-2}
DKDT_BKG	tyx	vertically integrated kinetic energy dissipation due to gravity wave background	W m^{-2}
DKDT_DYN	tyx	vertically integrated kinetic energy tendency due to dynamics	W m^{-2}
DKDT_GWD	tyx	vertically integrated kinetic energy tendency across gwd	W m^{-2}
DKDT_GWDRES	tyx	vertically integrated kinetic energy residual for total energy conservation	W m^{-2}
DKDT_INT	tyx	vertically integrated kinetic energy dissipation due to diffusion	W m^{-2}
DKDT_MST	tyx	vertically integrated kinetic energy tendency across moist	W m^{-2}
DKDT_ORO	tyx	vertically integrated kinetic energy dissipation due to orographic gravity waves	W m^{-2}
DKDT_PHY	tyx	vertically integrated kinetic energy tendency due to physics	W m^{-2}
DKDT_PHYPHY	tyx	vertically integrated kinetic energy tendency across physics	W m^{-2}
DKDT_RAY	tyx	vertically integrated kinetic energy dissipation due to Rayleigh friction	W m^{-2}
DKDT_SRF	tyx	vertically integrated kinetic energy dissipation due to surface friction	W m^{-2}
DKDT_TOP	tyx	vertically integrated kinetic energy dissipation due to topographic friction	W m^{-2}
DKDT_TRB	tyx	vertically integrated kinetic energy tendency across turbulence	W m^{-2}
DMDT_ANA	tyx	vertically integrated mass tendency due to analysis	kg m^{-2} s^{-1}
DMDT_DYN	tyx	vertically integrated mass tendency due to dynamics	kg m^{-2} s^{-1}
DMDT_PHY	tyx	vertically integrated mass tendency due to physics	kg m^{-2} s^{-1}
DOXDT_ANA	tyx	vertically integrated ozone tendency due to analysis	kg m^{-2} s^{-1}

DOXDT_CHM	tyx	vertically integrated odd oxygen tendency due to chemistry	kg m^{-2} s^{-1}
DOXDT_DYN	tyx	vertically integrated ozone tendency due to dynamics	kg m^{-2} s^{-1}
DOXDT_FIL	tyx	vertically integrated ox adjustment from filling	kg m^{-2} s^{-1}
DOXDT_PHY	tyx	vertically integrated odd oxygen tendency due to physics	kg m^{-2} s^{-1}
DPDT_ANA	tyx	mountain work tendency due to analysis	W m^{-2}
DPDT_DYN	tyx	mountain work tendency due to dynamics	W m^{-2}
DPDT_PHY	tyx	mountain work tendency due to physics	W m^{-2}
DQIDT_ANA	tyx	vertically integrated ice water tendency due to analysis	kg m^{-2} s^{-1}
DQIDT_DYN	tyx	vertically integrated ice water tendency due to dynamics	kg m^{-2} s^{-1}
DQIDT_FIL	tyx	vertically integrated qi adjustment from filling	kg m^{-2} s^{-1}
DQIDT_MST	tyx	vertically integrated ice tendency due to moist processes	kg m^{-2} s^{-1}
DQIDT_PHY	tyx	vertically integrated ice tendency due to physics	kg m^{-2} s^{-1}
DQLDT_ANA	tyx	vertically integrated liquid water tendency due to analysis	kg m^{-2} s^{-1}
DQLDT_DYN	tyx	vertically integrated liquid water tendency due to dynamics	kg m^{-2} s^{-1}
DQLDT_FIL	tyx	vertically integrated ql adjustment from filling	kg m^{-2} s^{-1}
DQLDT_MST	tyx	vertically integrated liquid water tendency due to moist processes	kg m^{-2} s^{-1}
DQLDT_PHY	tyx	vertically integrated liquid water tendency due to physics	kg m^{-2} s^{-1}
DQVDT_ANA	tyx	vertically integrated water vapor tendency due to analysis	kg m^{-2} s^{-1}
DQVDT_CHM	tyx	vertically integrated water vapor tendency due to chemistry	kg m^{-2} s^{-1}
DQVDT_DYN	tyx	vertically integrated water vapor tendency due to dynamics	kg m^{-2} s^{-1}
DQVDT_FIL	tyx	vertically integrated qv adjustment from filling	kg m^{-2} s^{-1}

DQVDT_MST	tyx	vertically integrated water vapor tendency due to moist processes	kg m^{-2} s^{-1}
DQVDT_PHY	tyx	vertically integrated water vapor tendency due to physics	kg m^{-2} s^{-1}
DQVDT_TRB	tyx	vertically integrated water vapor tendency due to turbulence	kg m^{-2} s^{-1}
DTHDT_ANA	tyx	vertically integrated THV tendency due to analysis	K kg m^{-2} s^{-1}
DTHDT_DYN	tyx	vertically integrated THV tendency due to dynamics	K kg m^{-2} s^{-1}
DTHDT_PHY	tyx	vertically integrated THV tendency due to physics	K kg m^{-2} s^{-1}
EVAP	tyx	evaporation from turbulence	kg m^{-2} s^{-1}
EVPCL	tyx	evaporation loss of cloud water	kg m^{-2} s^{-1}
EVPRN	tyx	evaporation loss of precip water	kg m^{-2} s^{-1}
FRZCL	tyx	net freezing of cloud condensate	kg m^{-2} s^{-1}
FRZRN	tyx	net freezing of precip condensate	kg m^{-2} s^{-1}
HFLUX	tyx	sensible heat flux from turbulence	W m^{-2}
LSCNVCI	tyx	statistical source of cloud ice	kg m^{-2} s^{-1}
LSCNVCL	tyx	statistical source of cloud water	kg m^{-2} s^{-1}
LSCNVRN	tyx	spurious rain from RH cleanup	kg m^{-2} s^{-1}
LWGNET	tyx	surface net downward longwave flux	W m^{-2}
LWTNET	tyx	upwelling longwave flux at toa	W m^{-2}
PRECCU	tyx	convective rainfall	kg m^{-2} s^{-1}
PRECLS	tyx	large scale rainfall	kg m^{-2} s^{-1}
PRECSN	tyx	snowfall	kg m^{-2} s^{-1}
QTFILL	tyx	vertically integrated total water adjustment from filling	kg m^{-2} s^{-1}
SDMCI	tyx	sedimentation loss of cloud ice	kg m^{-2} s^{-1}
SUBCI	tyx	sumblimation loss of cloud ice	kg m^{-2} s^{-1}
SUBSN	tyx	sumblimation loss of precip ice	kg m^{-2} s^{-1}

SWNETSRF	tyx	surface net downward shortwave flux	W m^{-2}
SWNETTOA	tyx	toa net downward shortwave flux	W m^{-2}
UFLXCPT	tyx	eastward flux of atmospheric enthalpy	J m^{-1} s^{-1}
UFLXKE	tyx	eastward flux of atmospheric kinetic energy	J m^{-1} s^{-1}
UFLXPHI	tyx	eastward flux of atmospheric potential energy	J m^{-1} s^{-1}
UFLXQI	tyx	eastward flux of atmospheric ice	kg m^{-1} s^{-1}
UFLXQL	tyx	eastward flux of atmospheric liquid water	kg m^{-1} s^{-1}
UFLXQV	tyx	eastward flux of atmospheric water vapor	kg m^{-1} s^{-1}
VFLXCPT	tyx	northward flux of atmospheric enthalpy	J m^{-1} s^{-1}
VFLXKE	tyx	northward flux of atmospheric kinetic energy	J m^{-1} s^{-1}
VFLXPHI	tyx	northward flux of atmospheric potential energy	J m^{-1} s^{-1}
VFLXQI	tyx	northward flux of atmospheric ice	kg m^{-1} s^{-1}
VFLXQL	tyx	northward flux of atmospheric liquid water	kg m^{-1} s^{-1}
VFLXQV	tyx	northward flux of atmospheric water vapor	kg m^{-1} s^{-1}

tavg1_2d_lfo_Nx (M2T1NXLFO): Land Surface Forcings

Frequency: *1-hourly from 00:30 UTC (time-averaged)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=24*
Granule Size: *~59 MB*

Name	*Dim*	*Description*	*Units*
LWGAB	tyx	surface absorbed longwave radiation	W m^{-2}
PARDF	tyx	surface downwelling par diffuse flux	W m^{-2}
PARDR	tyx	surface downwelling par beam flux	W m^{-2}
PRECCUCORR	tyx	liquid water convective precipitation, bias corrected	kg m^{-2} s^{-1}
PRECLSCORR	tyx	liquid water large scale precipitation, bias corrected	kg m^{-2} s^{-1}
PRECSNOCORR	tyx	Snowfall, bias corrected	kg m^{-2} s^{-1}
SWGDN	tyx	Incident shortwave land	W m^{-2}
SWLAND	tyx	Net shortwave land	W m^{-2}

tavg1_2d_lnd_Nx (M2T1NXLND): Land Surface Diagnostics

Frequency: *1-hourly from 00:30 UTC (time-averaged)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=24*
Granule Size: *~200 MB*

Name	*Dim*	*Description*	*Units*
BASEFLOW	tyx	baseflow flux	kg m^{-2} s^{-1}
ECHANGE	tyx	rate of change of total land energy	W m^{-2}
EVLAND	tyx	Evaporation land	kg m^{-2} s^{-1}
EVPINTR	tyx	interception loss energy flux	W m^{-2}
EVPSBLN	tyx	snow ice evaporation energy flux	W m^{-2}
EVPSOIL	tyx	baresoil evap energy flux	W m^{-2}
EVPTRNS	tyx	transpiration energy flux	W m^{-2}
FRSAT	tyx	fractional area of saturated zone	1
FRSNO	tyx	fractional area of land snowcover	1
FRUNST	tyx	fractional area of unsaturated zone	1
FRWLT	tyx	fractional area of wilting zone	1
GHLAND	tyx	Ground heating land	W m^{-2}
GRN	tyx	greeness fraction	1
GWETPROF	tyx	ave prof soil moisture	1
GWETROOT	tyx	root zone soil wetness	1
GWETTOP	tyx	surface soil wetness	1
LAI	tyx	leaf area index	1
LHLAND	tyx	Latent heat flux land	W m^{-2}
LWLAND	tyx	Net longwave land	W m^{-2}
PARDFLAND	tyx	surface downwelling par diffuse flux	W m^{-2}

PARDRLAND	tyx	surface downwelling par beam flux	W m^{-2}
PRECSNOLAND	tyx	snowfall land; bias corrected	kg m^{-2} s^{-1}
PRECTOTLAND	tyx	Total precipitation land; bias corrected	kg m^{-2} s^{-1}
PRMC	tyx	water profile	m^{-3} m^{-3}
QINFIL	tyx	Soil water infiltration rate	kg m^{-2} s^{-1}
RUNOFF	tyx	overland runoff including throughflow	kg m^{-2} s^{-1}
RZMC	tyx	water root zone	m^{-3} m^{-3}
SFMC	tyx	water surface layer	m^{-3} m^{-3}
SHLAND	tyx	Sensible heat flux land	W m^{-2}
SMLAND	tyx	Snowmelt flux land	kg m^{-2} s^{-1}
SNODP	tyx	snow depth	m
SNOMAS	tyx	Total snow storage land	kg m^{-2}
SPLAND	tyx	rate of spurious land energy source	W m^{-2}
SPSNOW	tyx	rate of spurious snow energy	W m^{-2}
SPWATR	tyx	rate of spurious land water source	kg m^{-2} s^{-1}
SWLAND	tyx	Net shortwave land	W m^{-2}
TELAND	tyx	Total energy storage land	J m^{-2}
TPSNOW	tyx	surface temperature of snow	K
TSAT	tyx	surface temperature of saturated zone	K
TSOIL1	tyx	soil temperatures layer 1	K
TSOIL2	tyx	soil temperatures layer 2	K
TSOIL3	tyx	soil temperatures layer 3	K
TSOIL4	tyx	soil temperatures layer 4	K
TSOIL5	tyx	soil temperatures layer 5	K
TSOIL6	tyx	soil temperatures layer 6	K
TSURF	tyx	surface temperature of land incl snow	K
TUNST	tyx	surface temperature of unsaturated zone	K
TWLAND	tyx	Avail water storage land	kg m^{-2}

TWLT	tyx	surface temperature of wilted zone	K
WCHANGE	tyx	rate of change of total land water	kg m^{-2} s^{-1}

tavg1_2d_ocn_Nx (M2T1NXOCN): Ocean Surface Diagnostics

Frequency: *1-hourly from 00:30 UTC (time-averaged)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=24*
Granule Size: *~113 MB*

Name	*Dim*	*Description*	*Units*
EFLUXICE	tyx	sea ice latent energy flux	W m^{-2}
EFLUXWTR	tyx	open water latent energy flux	W m^{-2}
FRSEAICE	tyx	ice covered fraction of tile	1
HFLUXICE	tyx	sea ice upward sensible heat flux	W m^{-2}
HFLUXWTR	tyx	open water upward sensible heat flux	W m^{-2}
LWGNTICE	tyx	sea ice net downward longwave flux	W m^{-2}
LWGNTWTR	tyx	open water net downward longwave flux	W m^{-2}
PRECSNOOCN	tyx	ocean snowfall	kg m^{-2} s^{-1}
QV10M	tyx	10-meter specific humidity	kg kg^{-1}
RAINOCN	tyx	ocean rainfall	kg m^{-2} s^{-1}
SWGNTICE	tyx	sea ice net downward shortwave flux	W m^{-2}
SWGNTWTR	tyx	open water net downward shortwave flux	W m^{-2}
T10M	tyx	10-meter air temperature	K
TAUXICE	tyx	eastward stress over ice	N m^{-2}
TAUXWTR	tyx	eastward stress over water	N m^{-2}
TAUYICE	tyx	northward stress over ice	N m^{-2}
TAUYWTR	tyx	northward stress over water	N m^{-2}
TSKINICE	tyx	sea ice skin temperature	K

TSKINWTR	tyx	open water skin temperature	K
U10M	tyx	10-meter eastward wind	m s^{-1}
V10M	tyx	10-meter northward wind	m s^{-1}

tavg1_2d_rad_Nx (M2T1NXRAD): Radiation Diagnostics

Frequency: *1-hourly from 00:30 UTC (time-averaged)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=24*
Granule Size: *~209 MB*

Name	*Dim*	*Description*	*Units*
ALBEDO	tyx	surface albedo	1
ALBNIRDF	tyx	surface albedo for near infrared diffuse	1
ALBNIRDR	tyx	surface albedo for near infrared beam	1
ALBVISDF	tyx	surface albedo for visible diffuse	1
ALBVISDR	tyx	surface albedo for visible beam	1
CLDHGH	tyx	cloud area fraction for high clouds	1
CLDLOW	tyx	cloud area fraction for low clouds	1
CLDMID	tyx	cloud area fraction for middle clouds	1
CLDTOT	tyx	total cloud area fraction	1
EMIS	tyx	surface emissivity	1
LWGAB	tyx	surface absorbed longwave radiation	W m^{-2}
LWGABCLR	tyx	surface absorbed longwave radiation assuming clear sky	W m^{-2}
LWGABCLRCLN	tyx	surface absorbed longwave radiation assuming clear sky and no aerosol	W m^{-2}
LWGEM	tyx	longwave flux emitted from surface	W m^{-2}
LWGNT	tyx	surface net downward longwave flux	W m^{-2}
LWGNTCLR	tyx	surface net downward longwave flux assuming clear sky	W m^{-2}

LWGNTCLRCLN	tyx	surface net downward longwave flux assuming clear sky and no aerosol	W m^{-2}
LWTUP	tyx	upwelling longwave flux at toa	W m^{-2}
LWTUPCLR	tyx	upwelling longwave flux at toa assuming clear sky	W m^{-2}
LWTUPCLRCLN	tyx	upwelling longwave flux at toa assuming clear sky and no aerosol	W m^{-2}
SWGDN	tyx	surface incoming shortwave flux	W m^{-2}
SWGDNCLR	tyx	surface incoming shortwave flux assuming clear sky	W m^{-2}
SWGNT	tyx	surface net downward shortwave flux	W m^{-2}
SWGNTCLN	tyx	surface net downward shortwave flux assuming no aerosol	W m^{-2}
SWGNTCLR	tyx	surface net downward shortwave flux assuming clear sky	W m^{-2}
SWGNTCLRCLN	tyx	surface net downward shortwave flux assuming clear sky and no aerosol	W m^{-2}
SWTDN	tyx	toa incoming shortwave flux	W m^{-2}
SWTNT	tyx	toa net downward shortwave flux	W m^{-2}
SWTNTCLN	tyx	toa net downward shortwave flux assuming no aerosol	W m^{-2}
SWTNTCLR	tyx	toa net downward shortwave flux assuming clear sky	W m^{-2}
SWTNTCLRCLN	tyx	toa net downward shortwave flux assuming clear sky and no aerosol	W m^{-2}
TAUHGH	tyx	in cloud optical thickness of high clouds(EXPORT)	1
TAULOW	tyx	in cloud optical thickness of low clouds	1
TAUMID	tyx	in cloud optical thickness of middle clouds	1
TAUTOT	tyx	in cloud optical thickness of all clouds	1
TS	tyx	surface skin temperature	K

tavg1_2d_slv_Nx (M2T1NXSLV): Single-Level Diagnostics

Frequency: *1-hourly from 00:30 UTC (time-averaged)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=24*
Granule Size: *~393 MB*

Name	*Dim*	*Description*	*Units*
CLDPRS	tyx	cloud top pressure	Pa
CLDTMP	tyx	cloud top temperature	K
DISPH	tyx	zero plane displacement height	m
H1000	tyx	height at 1000 mb	m
H250	tyx	height at 250 hPa	m
H500	tyx	height at 500 hPa	m
H850	tyx	height at 850 hPa	m
OMEGA500	tyx	omega at 500 hPa	Pa s^{-1}
PBLTOP	tyx	pbltop pressure	Pa
PS	tyx	surface pressure	Pa
Q250	tyx	specific humidity at 250 hPa	kg kg^{-1}
Q500	tyx	specific humidity at 500 hPa	kg kg^{-1}
Q850	tyx	specific humidity at 850 hPa	kg kg^{-1}
QV10M	tyx	10-meter specific humidity	kg kg^{-1}
QV2M	tyx	2-meter specific humidity	kg kg^{-1}
SLP	tyx	sea level pressure	Pa
T10M	tyx	10-meter air temperature	K
T250	tyx	air temperature at 250 hPa	K
T2M	tyx	2-meter air temperature	K
T2MDEW	tyx	dew point temperature at 2 m	K

T2MWET	tyx	wet bulb temperature at 2 m	K
T500	tyx	air temperature at 500 hPa	K
T850	tyx	air temperature at 850 hPa	K
TO3	tyx	total column ozone	Dobsons
TOX	tyx	total column odd oxygen	kg m^{-2}
TQI	tyx	total precipitable ice water	kg m^{-2}
TQL	tyx	total precipitable liquid water	kg m^{-2}
TQV	tyx	total precipitable water vapor	kg m^{-2}
TROPPB	tyx	tropopause pressure based on blended estimate	Pa
TROPPT	tyx	tropopause pressure based on thermal estimate	Pa
TROPPV	tyx	tropopause pressure based on EPV estimate	Pa
TROPQ	tyx	tropopause specific humidity using blended TROPP estimate	kg kg^{-1}
TROPT	tyx	tropopause temperature using blended TROPP estimate	K
TS	tyx	surface skin temperature	K
U10M	tyx	10-meter eastward wind	m s^{-1}
U250	tyx	eastward wind at 250 hPa	m s^{-1}
U2M	tyx	2-meter eastward wind	m s^{-1}
U500	tyx	eastward wind at 500 hPa	m s^{-1}
U50M	tyx	eastward wind at 50 meters	m s^{-1}
U850	tyx	eastward wind at 850 hPa	m s^{-1}
V10M	tyx	10-meter northward wind	m s^{-1}
V250	tyx	northward wind at 250 hPa	m s^{-1}
V2M	tyx	2-meter northward wind	m s^{-1}
V500	tyx	northward wind at 500 hPa	m s^{-1}
V50M	tyx	northward wind at 50 meters	m s^{-1}
V850	tyx	northward wind at 850 hPa	m s^{-1}
ZLCL	tyx	lifting condensation level	m

tavg3_2d_glc_Nx (M2T3NXGLC): Land Ice Surface Diagnostics

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *2D, single-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, time=8*
Granule Size: *~4 MB*

Name	*Dim*	*Description*	*Units*
ASNOW_GL	tyx	fractional area of glaciated surface snowcover	1
RUNOFF	tyx	runoff flux	kg m^{-2} s^{-1}
SNICEALB	tyx	aggregated snow ice broadband albedo	1
SNOMAS_GL	tyx	snow mass over glaciated surface	kg m^{-2}
SNOWDP_GL	tyx	snow depth over glaciated surface	m
WESNEXT	tyx	total snow mass residual due to densification	kg m^{-2} s^{-1}
WESNSC	tyx	top snow layer mass change due to sub con	kg m^{-2} s^{-1}

Time Averaged Three-Dimensional Collections

tavg3_3d_asm_Nv (M2T3NVASM): Assimilated Meteorological Fields

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, model-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=72, time=8*
Granule Size: *~2.1 GB*

Name	*Dim*	*Description*	*Units*
CLOUD	tzyx	cloud fraction for radiation	1
DELP	tzyx	pressure thickness	Pa
EPV	tzyx	ertels potential vorticity	K m^2 kg^{-1} s^{-1}

H	tzyx	mid layer heights	m
O3	tzyx	ozone mass mixing ratio	kg kg^{-1}
OMEGA	tzyx	vertical pressure velocity	Pa s^{-1}
PHIS	tyx	surface geopotential height	m^2 s^{-2}
PL	tzyx	mid level pressure	Pa
PS	tyx	surface pressure	Pa
QI	tzyx	mass fraction of cloud ice water	kg kg^{-1}
QL	tzyx	mass fraction of cloud liquid water	kg kg^{-1}
QV	tzyx	specific humidity	kg kg^{-1}
RH	tzyx	relative humidity after moist	1
SLP	tyx	sea level pressure	Pa
T	tzyx	air temperature	K
U	tzyx	eastward wind	m s^{-1}
V	tzyx	northward wind	m s^{-1}

tavg3_3d_cld_Np (M2T3NPCLD): Cloud Diagnostics

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, pressure-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=42, time=8*
Granule Size: *~446 MB*

Name	*Dim*	*Description*	*Units*
CFCU	tzyx	updraft areal fraction	1
CLOUD	tzyx	cloud fraction for radiation	1
DTRAIN	tzyx	detraining mass flux	kg m^{-2} s^{-1}
INCLOUDQI	tzyx	in cloud cloud ice for radiation	kg kg^{-1}
INCLOUDQL	tzyx	in cloud cloud liquid for radiation	kg kg^{-1}
QI	tzyx	mass fraction of cloud ice water	kg kg^{-1}

QL	tzyx	mass fraction of cloud liquid water	kg kg^{-1}
RH	tzyx	relative humidity after moist	1
TAUCLI	tzyx	in cloud optical thickness for ice clouds	1
TAUCLW	tzyx	in cloud optical thickness for liquid clouds	1

tavg3_3d_cld_Nv (M2T3NVCLD): Cloud Diagnostics

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, model-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=72, time=8*
Granule Size: *~691 MB*

Name	***Dim***	***Description***	***Units***
CFCU	tzyx	updraft areal fraction	1
CLOUD	tzyx	cloud fraction for radiation	1
DELP	tzyx	pressure thickness	Pa
DTRAIN	tzyx	detraining mass flux	kg m^{-2} s^{-1}
INCLOUDQI	tzyx	in cloud cloud ice for radiation	kg kg^{-1}
INCLOUDQL	tzyx	in cloud cloud liquid for radiation	kg kg^{-1}
PS	tyx	surface pressure	Pa
QI	tzyx	mass fraction of cloud ice water	kg kg^{-1}
QL	tzyx	mass fraction of cloud liquid water	kg kg^{-1}
RH	tzyx	relative humidity after moist	1
TAUCLI	tzyx	in cloud optical thickness for ice clouds	1
TAUCLW	tzyx	in cloud optical thickness for liquid clouds	1

tavg3_3d_mst_Ne (M2T3NEMST): Moist Processes Diagnostics

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, model-level edge, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=73, time=8*
Granule Size: *~253 MB*

Name	*Dim*	*Description*	*Units*
CMFMC	tzyx	cumulative mass flux	kg m^{-2} s^{-1}
PFICU	tzyx	3D flux of ice convective precipitation	kg m^{-2} s^{-1}
PFILSAN	tzyx	3D flux of ice nonconvective precipitation	kg m^{-2} s^{-1}
PFLCU	tzyx	3D flux of liquid convective precipitation	kg m^{-2} s^{-1}
PFLLSAN	tzyx	3D flux of liquid nonconvective precipitation	kg m^{-2} s^{-1}
PLE	tzyx	edge pressure	Pa

tavg3_3d_mst_Np (M2T3NPMST): Moist Processes Diagnostics

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, pressure-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=42, time=8*
Granule Size: *~305 MB*

Name	*Dim*	*Description*	*Units*
CMFMC	tzyx	cumulative mass flux	kg m^{-2} s^{-1}
DQRCU	tzyx	convective rainwater source	kg kg^{-1} s^{-1}
DQRLSAN	tzyx	large scale rainwater source	kg kg^{-1} s^{-1}
PFICU	tzyx	3D flux of ice convective precipitation	kg m^{-2} s^{-1}
PFILSAN	tzyx	3D flux of ice nonconvective precipitation	kg m^{-2} s^{-1}

PFLCU	tzyx	3D flux of liquid convective precipitation	kg m^{-2} s^{-1}
PFLLSAN	tzyx	3D flux of liquid nonconvective precipitation	kg m^{-2} s^{-1}
REEVAPCN	tzyx	evap subl of convective precipitation	kg kg^{-1} s^{-1}
REEVAPLSAN	tzyx	evap subl of non convective precipitation	kg kg^{-1} s^{-1}

tavg3_3d_mst_Nv (M2T3NVMST): Moist Processes Diagnostics

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, model-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=72, time=8*
Granule Size: *~275 MB*

Name	*Dim*	*Description*	*Units*
DELP	tzyx	pressure thickness	Pa
DQRCU	tzyx	convective rainwater source	kg kg^{-1} s^{-1}
DQRLSAN	tzyx	large scale rainwater source	kg kg^{-1} s^{-1}
PS	tyx	surface pressure	Pa
REEVAPCN	tzyx	evap subl of convective precipitation	kg kg^{-1} s^{-1}
REEVAPLSAN	tzyx	evap subl of non convective precipitation	kg kg^{-1} s^{-1}

tavg3_3d_nav_Ne (M2T3NENAV): Vertical Coordinates (Edges)

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, model-level edge, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=73, time=8*
Granule Size: *~185 MB*

Name	*Dim*	*Description*	*Units*
PLE	tzyx	edge pressure	Pa
ZLE	tzyx	edge heights	m

tavg3_3d_odt_Np (M2T3NPODT): Ozone Tendencies

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, pressure-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=42, time=8*
Granule Size: *~502 MB*

Name	*Dim*	*Description*	*Units*
DOXDTANA	tzyx	total ozone analysis tendency	mol mol^{-1} s^{-1}
DOXDTCHM	tzyx	tendency of odd oxygen mixing ratio due to chemistry	mol mol^{-1} s^{-1}
DOXDTDYN	tzyx	tendency of ozone due to dynamics	kg kg^{-1} s^{-1}
DOXDTMST	tzyx	tendency of odd oxygen due to moist processes	kg kg^{-1} s^{-1}
DOXDTTRB	tzyx	tendency of odd oxygen due to turbulence	kg kg^{-1} s^{-1}

tavg3_3d_qdt_Np (M2T3NPQDT): Moist Tendencies

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, pressure-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=42, time=8*
Granule Size: *~693 MB*

Name	*Dim*	*Description*	*Units*
DQIDTDYN	tzyx	tendency of ice water due to dynamics	kg kg^{-1} s^{-1}
DQIDTMST	tzyx	total ice water tendency due to moist	kg kg^{-1} s^{-1}
DQIDTTRB	tzyx	tendency of frozen condensate due to turbulence	kg kg^{-1} s^{-1}
DQLDTDYN	tzyx	tendency of liquid water due to dynamics	kg kg^{-1} s^{-1}
DQLDTMST	tzyx	total liq water tendency due to moist	kg kg^{-1} s^{-1}
DQLDTTRB	tzyx	tendency of liquid condensate due to turbulence	kg kg^{-1} s^{-1}
DQVDTANA	tzyx	total specific humidity analysis tendency	kg kg^{-1} s^{-1}

DQVDTCHM	tzyx	tendency of water vapor mixing ratio due to chemistry	kg kg^{-1} s^{-1}
DQVDTDYN	tzyx	tendency of specific humidity due to dynamics	kg kg^{-1} s^{-1}
DQVDTMST	tzyx	specific humidity tendency due to moist	kg kg^{-1} s^{-1}
DQVDTTRB	tzyx	tendency of specific humidity due to turbulence	kg kg^{-1} s^{-1}

tavg3_3d_rad_Np (M2T3NPRAD): Radiation Diagnostics

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, pressure-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=42, time=8*
Granule Size: *~422 MB*

Name	*Dim*	*Description*	*Units*
CLOUD	tzyx	cloud fraction for radiation	1
DTDTLWR	tzyx	air temperature tendency due to longwave	K s^{-1}
DTDTLWRCLR	tzyx	air temperature tendency due to longwave for clear skies	K s^{-1}
DTDTSWR	tzyx	air temperature tendency due to shortwave	K s^{-1}
DTDTSWRCLR	tzyx	air temperature tendency due to shortwave for clear skies	K s^{-1}

tavg3_3d_rad_Nv (M2T3NVRAD): Radiation Diagnostics

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, model-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=72, time=8*
Granule Size: *~758 MB*

Name	*Dim*	*Description*	*Units*
CLOUD	tzyx	cloud fraction for radiation	1
DELP	tzyx	pressure thickness	Pa
DTDTLWR	tzyx	air temperature tendency due to longwave	K s^{-1}

DTDTLWRCLR	tzyx	air temperature tendency due to longwave for clear skies	K s^{-1}
DTDTSWR	tzyx	air temperature tendency due to shortwave	K s^{-1}
DTDTSWRCLR	tzyx	air temperature tendency due to shortwave for clear skies	K s^{-1}
PS	tyx	surface pressure	Pa

tavg3_3d_tdt_Np (M2T3NPTDT): Temperature Tendencies

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, pressure-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=42, time=8*
Granule Size: *~1016 MB*

Name	*Dim*	*Description*	*Units*
DTDTANA	tzyx	total temperature analysis tendency	K s^{-1}
DTDTDYN	tzyx	tendency of air temperature due to dynamics	K s^{-1}
DTDTFRI	tzyx	tendency of air temperature due to friction	K s^{-1}
DTDTGWD	tzyx	air temperature tendency due to GWD	K s^{-1}
DTDTMST	tzyx	tendency of air temperature due to moist processes	K s^{-1}
DTDTRAD	tzyx	tendency of air temperature due to radiation	K s^{-1}
DTDTTOT	tzyx	tendency of air temperature due to physics	K s^{-1}
DTDTTRB	tzyx	tendency of air temperature due to turbulence	K s^{-1}

tavg3_3d_trb_Ne (M2T3NETRB): Turbulence Diagnostics

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, model-level edge, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=73, time=8*
Granule Size: *~1.5 GB*

Name	*Dim*	*Description*	*Units*
KH	tzyx	total scalar diffusivity	$m^2 s^{-1}$
KHLK	tzyx	entrainment heat diffusivity from Lock	$m^2 s^{-1}$
KHLS	tzyx	scalar diffusivity from Louis	$m^2 s^{-1}$
KHRAD	tzyx	radiation driven scalar diffusivity from Lock scheme	$m^2 s^{-1}$
KHSFC	tzyx	surface driven scalar diffusivity from Lock scheme	$m^2 s^{-1}$
KM	tzyx	total momentum diffusivity	$m^2 s^{-1}$
KMLK	tzyx	entrainment momentum diffusivity from Lock	$m^2 s^{-1}$
KMLS	tzyx	momentum diffusivity from Louis	$m^2 s^{-1}$
PLE	tzyx	edge pressure	Pa
RI	tzyx	Richardson number from Louis	1

tavg3_3d_trb_Np (M2T3NPTRB): Turbulence Diagnostics

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, pressure-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=42, time=8*
Granule Size: *~820 MB*

Name	*Dim*	*Description*	*Units*
KH	tzyx	total scalar diffusivity	$m^2 s^{-1}$
KHLK	tzyx	entrainment heat diffusivity from Lock	$m^2 s^{-1}$
KHLS	tzyx	scalar diffusivity from Louis	$m^2 s^{-1}$
KHRAD	tzyx	radiation driven scalar diffusivity from Lock scheme	$m^2 s^{-1}$
KHSFC	tzyx	surface driven scalar diffusivity from Lock scheme	$m^2 s^{-1}$
KM	tzyx	total momentum diffusivity	$m^2 s^{-1}$
KMLK	tzyx	entrainment momentum diffusivity from Lock	$m^2 s^{-1}$
KMLS	tzyx	momentum diffusivity from Louis	$m^2 s^{-1}$
RI	tzyx	Richardson number from Louis	1

tavg3_3d_udt_Np (M2T3NPUDT): Wind Tendencies

Frequency: *3-hourly from 01:30 UTC (time-averaged)*
Spatial Grid: *3D, pressure-level, full horizontal resolution*
Dimensions: *longitude=576, latitude=361, level=42, time=8*
Granule Size: *~1.1 GB*

Name	***Dim***	***Description***	***Units***
DUDTANA	tzyx	total eastward wind analysis tendency	m s^{-2}
DUDTDYN	tzyx	tendency of eastward wind due to dynamics	m s^{-2}
DUDTGWD	tzyx	tendency of eastward wind due to GWD	m s^{-2}
DUDTMST	tzyx	zonal wind tendency due to moist	m s^{-2}
DUDTTRB	tzyx	tendency of eastward wind due to turbulence	m s^{-2}
DVDTANA	tzyx	total northward wind analysis tendency	m s^{-2}
DVDTDYN	tzyx	tendency of northward wind due to dynamics	m s^{-2}
DVDTGWD	tzyx	tendency of northward wind due to GWD	m s^{-2}
DVDTMST	tzyx	meridional wind tendency due to moist	m s^{-2}
DVDTTRB	tzyx	tendency of northward wind due to turbulence	m s^{-2}

Digital Object Identifier (DOI) Tables

Digital Object Identifiers are attached to each MERRA-2 variable collection. Users should cite the data used in research papers following these DOI's.

Example Citation:

Global Modeling and Assimilation Office (GMAO) (2015), *inst3_3d_asm_Cp: MERRA-2 3D IAU State, Meteorology Instantaneous 3-hourly (p-coord, 0.625x0.5L42), version 5.12.4*, Greenbelt, MD, USA: Goddard Space Flight Center Distributed Active Archive Center (GSFC DAAC), Accessed **Enter User Data Access Date** at doi: 10.5067/VJAFPLI1CSIV.

Note that complete citations for each file collection are provided at the GES-DISC download site.

See next page:

Table 6.1 DOI’s for MERRA-2 hourly file collections.

Descriptive ShortName	ShortName	DOI NAME
inst1_2d_asm_Nx	M2I1NXASM	10.5067/3Z173KIE2TPD
inst1_2d_int_Nx	M2I1NXINT	10.5067/G0U6NGQ3BLE0
inst1_2d_lfo_Nx	M2I1NXLFO	10.5067/RCMZA6TL70BG
inst3_3d_asm_Np	M2I3NPASM	10.5067/QBZ6MG944HW0
inst3_3d_aer_Nv	M2I3NVAER	10.5067/LTVB4GPCOTK2
inst3_3d_asm_Nv	M2I3NVASM	10.5067/WWQSXQ8IVFW8
inst3_3d_chm_Nv	M2I3NVCHM	10.5067/HO9OVZWF3KW2
inst3_3d_gas_Nv	M2I3NVGAS	10.5067/96BUID8HGGX5
inst3_2d_gas_Nx	M2I3NXGAS	10.5067/HNGA0EWW0R09
inst6_3d_ana_Np	M2I6NPANA	10.5067/A7S6XP56VZWS
inst6_3d_ana_Nv	M2I6NVANA	10.5067/IUUF4WB9FT4W
statD_2d_slv_Nx	M2SDNXSLV	10.5067/9SC1VNTWGWV3
tavg1_2d_adg_Nx	M2T1NXADG	10.5067/HM00OHQBHKTP
tavg1_2d_aer_Nx	M2T1NXAER	10.5067/KLICLTZ8EM9D
tavg1_2d_chm_Nx	M2T1NXCHM	10.5067/3RQ5YS674DGQ
tavg1_2d_csp_Nx	M2T1NXCSP	10.5067/H0VVAD8F6MX5
tavg1_2d_flx_Nx	M2T1NXFLX	10.5067/7MCPBJ41Y0K6
tavg1_2d_int_Nx	M2T1NXINT	10.5067/Q5GVUVUIVGO7
tavg1_2d_lfo_Nx	M2T1NXLFO	10.5067/L0T5GEG1NYFA
tavg1_2d_lnd_Nx	M2T1NXLND	10.5067/RKPHT8KC1Y1T
tavg1_2d_ocn_Nx	M2T1NXOCN	10.5067/Y67YQ1L3ZZ4R
tavg1_2d_rad_Nx	M2T1NXRAD	10.5067/Q9QMY5PBNV1T
tavg1_2d_slv_Nx	M2T1NXSLV	10.5067/VJAFPLI1CSIV
tavg3_3d_mst_Ne	M2T3NEMST	10.5067/JRUZ3SJ3ZJ72
tavg3_3d_trb_Ne	M2T3NETRB	10.5067/4I7ZI35QRH8K
tavg3_3d_nav_Ne	M2T3NENAV	10.5067/N5WAKNS1UYQN
tavg3_3d_cld_Np	M2T3NPCLD	10.5067/TX10URJSKT53
tavg3_3d_mst_Np	M2T3NPMST	10.5067/0TUFO90Q2PMS
tavg3_3d_rad_Np	M2T3NPRAD	10.5067/3UGE8WQXZAOK
tavg3_3d_tdt_Np	M2T3NPTDT	10.5067/9NCR9DDDOPFI
tavg3_3d_trb_Np	M2T3NPTRB	10.5067/ZRRJPGWL8AVL
tavg3_3d_udt_Np	M2T3NPUDT	10.5067/CWV0G3PPPWFW
tavg3_3d_odt_Np	M2T3NPODT	10.5067/S0LYTK57786Z
tavg3_3d_qdt_Np	M2T3NPQDT	10.5067/A9KWADY78YHQ
tavg3_3d_asm_Nv	M2T3NVASM	10.5067/SUOQESM06LPK
tavg3_3d_cld_Nv	M2T3NVCLD	10.5067/F9353J0FAHIH
tavg3_3d_mst_Nv	M2T3NVMST	10.5067/ZXTJ28TQR1TR
tavg3_3d_rad_Nv	M2T3NVRAD	10.5067/7GFQKO1T43RW
tavg3_2d_glc_Nx	M2T3NXGLC	10.5067/9ETB4TT5J6US

Table 6.2 DOI's for MERRA-2 monthly mean file collections.

Descriptive ShortName	ShortName	DOI NAME
instM_2d_asm_Nx	M2IMNXASM	10.5067/5ESKGQTZG7FO
instM_2d_int_Nx	M2IMNXINT	10.5067/KVTU1A8BWFSJ
instM_2d_lfo_Nx	M2IMNXLFO	10.5067/11F99Y6TXN99
instM_2d_gas_Nx	M2IMNXGAS	10.5067/XOGNBQEPLUC5
instM_3d_asm_Np	M2IMNPASM	10.5067/2E096JV59PK7
instM_3d_ana_Np	M2IMNPANA	10.5067/V92O8XZ30XBI
tavgM_2d_adg_Nx	M2TMNXADG	10.5067/RZIK2TV7PP38
tavgM_2d_aer_Nx	M2TMNXAER	10.5067/FH9A0MLJPC7N
tavgM_2d_chm_Nx	M2TMNXCHM	10.5067/WMT31RKEXK8I
tavgM_2d_csp_Nx	M2TMNXCSP	10.5067/BZPOTGJOQKLU
tavgM_2d_flx_Nx	M2TMNXFLX	10.5067/0JRLVL8YV2Y4
tavgM_2d_int_Nx	M2TMNXINT	10.5067/FQPTQ4OJ22TL
tavgM_2d_lfo_Nx	M2TMNXLFO	10.5067/5V7K6LJD44SY
tavgM_2d_lnd_Nx	M2TMNXLND	10.5067/8S35XF81C28F
tavgM_2d_ocn_Nx	M2TMNXOCN	10.5067/4IASLIDL8EEC
tavgM_2d_rad_Nx	M2TMNXRAD	10.5067/OU3HJDS973O0
tavgM_2d_slv_Nx	M2TMNXSLV	10.5067/AP1B0BA5PD2K
tavgM_2d_glc_Nx	M2TMNXGLC	10.5067/5W8Q3I9WUFGX
tavgM_3d_cld_Np	M2TMNPCLD	10.5067/J9R0LXGH48JR
tavgM_3d_mst_Np	M2TMNPMST	10.5067/ZRZGD0DCK1CG
tavgM_3d_rad_Np	M2TMNPRAD	10.5067/H3YGROBVBGFJ
tavgM_3d_tdt_Np	M2TMNPTDT	10.5067/VILT59HI2MOY
tavgM_3d_trb_Np	M2TMNPTRB	10.5067/2YOIQB5C3ACN
tavgM_3d_udt_Np	M2TMNPUDT	10.5067/YSR6IA5057XX
tavgM_3d_odt_Np	M2TMNPODT	10.5067/Z2KCWAV4GPD2
tavgM_3d_qdt_Np	M2TMNPQDT	10.5067/2ZTU87V69ATP
statM_2d_slv_Nx	M2SMNXSLV	10.5067/KVIMOMCUO83U
const_2d_asm_NX	M2C0NXASM	10.5067/ME5QX6Q5IGGU

Table 6.3 DOI’s for MERRA-2 monthly diurnal mean file collections.

Descriptive ShortName	ShortName	DOI NAME
instU_2d_asm_Nx	M2IUNXASM	10.5067/BOJSTZAO2L8R
instU_2d_int_Nx	M2IUNXINT	10.5067/DGAB3HFEYMLY
instU_2d_lfo_Nx	M2IUNXLFO	10.5067/FC3BVJ88Y8A2
instU_2d_gas_Nx	M2IUNXGAS	10.5067/TVJ4MHBED39L
instU_3d_asm_Np	M2IUNPASM	10.5067/6EGRBNEBMIYS
instU_3d_ana_Np	M2IUNPANA	10.5067/TRD91YO9S6E7
tavgU_2d_adg_Nx	M2TUNXADG	10.5067/YZJJXZTFCX6B
tavgU_2d_aer_Nx	M2TUNXAER	10.5067/KPUMVXFEQLA1
tavgU_2d_chm_Nx	M2TUNXCHM	10.5067/5KFZ6GXRHZKN
tavgU_2d_csp_Nx	M2TUNXCSP	10.5067/9PH5QU4CL9E8
tavgU_2d_flx_Nx	M2TUNXFLX	10.5067/LUHPNWAKYIO3
tavgU_2d_int_Nx	M2TUNXINT	10.5067/R2MPVU4EOSWT
tavgU_2d_lfo_Nx	M2TUNXLFO	10.5067/BTSNKAJND3ME
tavgU_2d_lnd_Nx	M2TUNXLND	10.5067/W0J15047CF6N
tavgU_2d_ocn_Nx	M2TUNXOCN	10.5067/KLNAVGAX7J66
tavgU_2d_rad_Nx	M2TUNXRAD	10.5067/4SDCJYK8P9QU
tavgU_2d_slv_Nx	M2TUNXSLV	10.5067/AFOK0TPEVQEK
tavgU_2d_glc_Nx	M2TUNXGLC	10.5067/7VUPQC736SWX
tavgU_3d_cld_Np	M2TUNPCLD	10.5067/EPW7T5UO0C0N
tavgU_3d_mst_Np	M2TUNPMST	10.5067/ZRSN0JU27DK2
tavgU_3d_rad_Np	M2TUNPRAD	10.5067/H140JMDOWB0Y
tavgU_3d_tdt_Np	M2TUNPTDT	10.5067/QPO9E5TPZ8OF
tavgU_3d_trb_Np	M2TUNPTRB	10.5067/2A99C60CG7WC
tavgU_3d_udt_Np	M2TUNPUDT	10.5067/DO715T7T5PG8
tavgU_3d_odt_Np	M2TUNPODT	10.5067/M8OJ09GZP23E
tavgU_3d_qdt_Np	M2TUNPQDT	10.5067/S8HJXIR0BFTS

Appendix: Budgets

In MERRA-2 the concatenation of the IAU corrector segments of each analysis cycle is equivalent to a single, continuous run of the AGCM with an additional term–the analysis tendency–on the right-hand-side of all equations that predict analyzed quantities. Budgets in MERRA-2 are thus identical to those in the free-running AGCM, with the addition of the effects of analysis tendencies, which are constant during the six-hour duration of each corrector segment.

The MERRA output includes a nearly* full accounting for the budgets of eight atmospheric quantities: the mass of the atmosphere, the mass of water in vapor, liquid, and ice forms, kinetic energy, the virtual enthalpy, virtual potential temperature, and the total mass of odd oxygen. We also keep exact budgets for total water and energy at the land surface. Aerosol budgets will be documented separately.

Atmospheric Budgets

The accounting for each of the eight atmospheric quantities is kept in two file collections: inst1_2d_int_Nx and tavg1_2d_int_Nx. Both collections consist of 2-dimensional data on the model's native horizontal grid, and both contain only vertical integrals. The first contains instantaneous mass-weighted vertical integrals of the eight quantities at the beginning of each hour (i.e., 00:00Z, 01:00Z, etc). The second collection contains various hourly-mean, vertically-integrated contributions to the tendencies of each quantity. This Appendix explains how these contributions can be combined to produce the local change in the quantity implied by values in the inst1_2d_int_Nx collection, how the contributions were computed, and what assumptions enter this accounting.

In the following, we will denote the finite-differenced, mass-weighted, vertical integrals of quantities by an overbar:

$$\overline{X} = \sum_{l=layers} X_l \delta m_l \,,$$

where $\delta m_l = m_d + m_v = \dfrac{\delta p_l}{g}$ is the mass of layer l, interpreted to be the sum of the mass of dry air and water vapor. Here δp_l is the pressure thickness of the layer and $\sum_{l=layers} \delta p_l = p_S - p_T$, where p_S is the surface pressure, and p_T is the pressure at the model's top (1 Pa).

* Some terms were not produced from the cube sphere grid dynamical core, and one term from the water vapor analysis was inadvertently left out of the water budget diagnostics.

Atmospheric Mass

The model satisfies the following conservation equation:

$$\frac{\partial M}{\partial t} = -\nabla \bullet (\overline{\underset{\rightarrow}{v}}) + \left[\frac{\partial M}{\partial t} \right]_{ANA}$$

The spatial distribution of the total atmospheric mass, $M = (p_S - p_T)/g$, is stored in the variable **MASS** in the inst1_2d_int_Nx collection. In the tavg1_2d_int_Nx collection, the total tendency is separated into contributions from dynamics (**DMDT_DYN)**, and analysis (**DMDT_ANA)**. These satisfy collection-variable equations such as:

$$\mathbf{MASS_{1:00Z} - MASS_{0:00Z} = 3600.\ (DMDT\_DYN + DMDT\_ANA)_{0:30Z}}$$

The finite-volume dynamics used in GEOS-5 conserves mass to within round-off at 64-bit precision, so the global mean of **DMDT_DYN** is effectively zero. The physics used in the GEOS-5 AGCM does not include changes in column mass due to changes in water content; there is, therefore, no physics contribution. Although the atmospheric physics does not include atmospheric water in its mass budget, realistic changes in atmospheric mass can still occur since the surface pressure is analyzed and surface pressure observations include the effect. Mass changes due to water content thus appear as analysis increments rather than physics increments. It is not clear how much improvement in the mass budget, as measured by the degree of invariance of dry mass, would be achieved if the atmospheric model had a more complete treatment.

Atmospheric Water

The model predicts water vapor (specific humidity) as well as cloud ice and liquid water. Only specific humidity is analyzed, but analysis tendencies of the condensates can occur through the analysis increments of atmospheric mass.

For each of these three quantities we have:

$$\frac{\partial \overline{q_{(v,l,i)}}}{\partial t} = -\nabla \bullet (\overline{\underset{\rightarrow}{v}\, q_{(v,l,i)}}) + \left[\frac{\partial \overline{q_{(v,l,i)}}}{\partial t} \right]_{PHY} + \left[\frac{\partial \overline{q_{(v,l,i)}}}{\partial t} \right]_{ANA}$$

The sum of the contributions obtained from the tavg1_2d_int_Nx collection exactly matches the difference of values in the inst1_2d_int_Nx. For example,

$$\mathbf{TQV_{1:00Z} - TQV_{0:00Z} = 3600\ \ (DQVDT\_DYN + DQVDT\_PHY + DQVDT\_ANA)_{0:30Z}}$$
$$\mathbf{TQL_{1:00Z} - TQL_{0:00Z} = 3600\ \ (DQLDT\_DYN + DQLDT\_PHY + DQLDT\_ANA)_{0:30Z}}$$
$$\mathbf{TQI_{1:00Z} - TQI_{0:00Z} = 3600\ \ (DQIDT\_DYN + DQIDT\_PHY + DQIDT\_ANA)_{0:30Z}}$$

The total atmospheric water, $w = q_v + q_l + q_i$, satisfies:

$$\frac{\partial \overline{w}}{\partial t} = -\nabla \bullet (\overline{\underset{\rightarrow}{v} w}) + (E - P) \quad + \quad \left[\frac{\partial \overline{w}}{\partial t}\right]_{FILL} \quad + \quad \left[\frac{\partial \overline{w}}{\partial t}\right]_{ANA}, \tag{6}$$

where $P = P_l^{cu} + P_l^{ls} + P_s$ is the total precipitation rate at the surface and includes contributions from convective and large-scale rain and snow; E is the upward turbulent water vapor flux at the surface; and the "filling" of spurious negative water is part of the physics contribution. In the model, surface turbulent fluxes of the condensates are assumed to be zero. In MERRA-2, the analysis also includes a constraint on the water vapor assimilation that prevents global mass variations that can occur with observing system changes (Takacs et al., 2015). The largest part of the mass constraint is in the vapor phase and is considered in the water vapor ANA term. However, secondary effects of the constraint were inadvertently left out of the ANA terms for solid and liquid phase, so that a small residual value will occur in these budgets. The contributions to total water from the dynamics, physics, and analysis are simply the sums of the corresponding terms in the three collection-variable equations. As implied by (6), the sum of the physics contributions to tendencies of the three phases of water also satisfies:

DQVDT_PHY + DQLDT_PHY + DQIDT_PHY =

EVAP– PRECCU – PRECLS – PRECSN + QTFILL.

The model ignores the storage of falling precipitation, so the production and loss terms of rain and snow must balance.

$$\begin{aligned} C_r^{cu} + C_r^{ls} + G_r^{coll} + G_r^{auto} - E_r - F_r &= P_l^{cu} + P_l^{ls} \\ G_s^{coll} + G_s^{sedm} - S_s + F_r &= P_s \end{aligned} \tag{7}$$

Here C_r^{cu} is the direct production of rain from vapor by the convection parameterization and C_r^{ls} is the direct production of rain from vapor by the large-scale condensation , $G_{r,s}^{coll}$ are the generation of rain and snow from collection of cloud liquid droplets, G_r^{auto} is the increase of rainwater by auto conversion of cloud liquid water, G_s^{sedm} is the increase in frozen precipitation from the sedimentation of cloud ice, E_r is evaporation of rain and S_s is the sublimation of frozen precipitation (snow), F_r is the net conversion between rain and snow due to freezing and melting, and $P_{r,s}$ are the rain and snow reaching the surface. The corresponding collection-variable equations are:

CUCNVRN + LSCNVRN + COLCNVRN +AUTCNVRN– EVPRN – FRZRN

= PRECCU + PRECLS

COLCNVSN + SDMCI - SUBSN + FRZRN = PRECSN

The sum of the two equations also satisfies

$$G_P - E_P = P,$$

where $G_P = C_r^{cu} + C_r^{ls} + G_r^{coll} + G_r^{auto} - G_s^{coll} + G_s^{sedm}$ is the total production of precipitation,

$E_P = E_r + S_s$ is the total evaporation and sublimation of rain and snow, and $P = P_l^{cu} + P_l^{ls} + P_s$ is the total precipitation reaching the surface. The corresponding collection-variable equation is:

PGENTOT – PREVTOT = PRECTOT ,

which are variables in the tavg1_2d_flx_Nx collection. This last balance is subject to greater round-off, since this collection has its precision degraded for compression.

The physics tendency of specific humidity is separated into contributions from moist processes, turbulence, chemistry (a small stratospheric source), and the numerical 'filling" of spurious negative values:

$$\left[\frac{\partial \overline{q_v}}{\partial t}\right]_{PHY} = \left[\frac{\partial \overline{q_v}}{\partial t}\right]_{MST} + \left[\frac{\partial \overline{q_v}}{\partial t}\right]_{TRB} + \left[\frac{\partial \overline{q_v}}{\partial t}\right]_{CHM} + \left[\frac{\partial \overline{q_v}}{\partial t}\right]_{FIL} .$$

The corresponding collection-variable equation is:

DQVDT_PHY = DQVDT_MST + DQVDT_TRB + DQVDT_CHM + DQVDT_FIL

Contributions from the moist and turbulence parameterizations can be written as:

$$\left[\frac{\partial \overline{q_v}}{\partial t}\right]_{MST} = -(C_r^{cu} + C_r^{ls} + C_l^{cu} + C_l^{ls} + C_i^{cu} + C_i^{ls}) + S_i + E_l + S_s + E_r ,$$

$$\left[\frac{\partial \overline{q_v}}{\partial t}\right]_{TRB} = E ,$$

In addition to the precipitation sources and sinks in (7), the contribution from moist processes includes the sources and sinks for cloud condensates. The terms C_r, C_l, and C_i are the direct conversions from water vapor to liquid precipitation, to cloud liquid, and to cloud ice, separated into cumulus and large-scale contributions; S_i and S_s is the vapor source from sublimation of cloud ice and snow; and E_l and E_r is the vapor source from evaporation of cloud liquid water and rain. The turbulence contribution is simply the evaporation from the surface, E. In terms of collection variables these are:

DQVDT_MST = – (CUCNVRN+LSCNVRN+CUCNVCL+LSCNVCL +CUCNVCI+LSCNVCI)
+ SUBCI + EVPCL + SUBSN + EVPRN

DQVDT_TRB = EVAP

The budgets for cloud liquid and cloud ice involve only terms from the moist processes and water filling. Although these are mixed by the turbulence, we ignore surface turbulent fluxes of cloud condensates.

$$\left[\frac{\partial \overline{q_{l,i}}}{\partial t}\right]_{PHY} = \left[\frac{\partial \overline{q_{l,i}}}{\partial t}\right]_{MST} + \left[\frac{\partial \overline{q_{l,i}}}{\partial t}\right]_{FIL} ,$$

And in equation variable form:

DQLDT_PHY = DQLDT_MST + DQLDT_FIL

DQIDT_PHY = DQIDT_MST + DQIDT_FIL.

The moist contributions can be written as:

$$\left[\frac{\partial \overline{q_l}}{\partial t}\right]_{MST} = C_l^{cu} + C_l^{ls} - (G_r^{coll} + G_r^{auto} + G_s^{coll}) - E_l - F_l,$$

$$\left[\frac{\partial \overline{q_i}}{\partial t}\right]_{MST} = C_i^{cu} + C_i^{ls} - G_s^{sedm} - S_i + F_l,$$

where F_l is the net freezing (freezing-melting) of cloud condensates. In terms of collection variables these are:

DQLDT_MST = CUCNVCL+ LSCNVCL – (COLCNVRN+AUTCNVRN+COLCNVSN) – EVPCL –FRZCL

DQIDT_MST = CUCNVCI+ LSCNVCI – SDMCI – SUBCI + FRZCL

Atmospheric Kinetic Energy

The instantaneous total kinetic energy for each grid column, $K = \overline{\frac{1}{2}|\underset{\rightarrow}{v}|^2}$ **,** is stored in the variable **KE** in the inst1_2d_int_Nx collection. In the tavg1_2d_int_Nx collection, the total tendency is separated into contributions from dynamics (**DKDT_DYN)**, physics (**DKDT_PHY)**, and analysis increments of winds and atmospheric mass (**DKDT_ANA)**.

$$\frac{\partial K}{\partial t} = \left[\frac{\partial K}{\partial t}\right]_{DYN} + \left[\frac{\partial K}{\partial t}\right]_{PHY} + \left[\frac{\partial K}{\partial t}\right]_{ANA} \tag{1}$$

The sum of the three contributions obtained from the tavg1_2d_int_Nx collection exactly matches the difference of values in the inst1_2d_int_Nx, since the contributions are computed by differencing K before and after each process is included. They thus satisfy collection-variable equations of the form:

$KE_{1:00Z}$ - $KE_{0:00Z}$ = 3600 (DKDT_DYN + DKDT_PHY + DKDT_ANA) $_{0:30Z}$.

The dynamical contribution can be further divided by considering the vertically integrated kinetic energy equation written in flux form. Ignoring contributions from the analysis and from explicit frictional processes that are included in the physics, this is:

$$\left[\frac{\partial K}{\partial t}\right]_{DYN} = -\nabla \bullet (\overline{\underset{\rightarrow}{v}\tfrac{1}{2}|\underset{\rightarrow}{v}|^2}) - \nabla \bullet (\overline{\underset{\rightarrow}{v}\phi}) - \overline{\omega\alpha} - \frac{\partial}{\partial t}(\phi_S p_S - \phi_T p_T) - Q_{NUM} \tag{2}$$

The first term on the right hand side of (2) is the contribution from the inertial terms in the momentum equations, which reduces to the vertically integrated convergence of the kinetic energy flux. The next three terms are the total work done by the pressure gradient. The $\overline{\omega\alpha}$ term, which appears with opposite sign in the thermodynamic equation, is the conversion between kinetic and total potential energy. The fourth term is the change in gravitational potential energy associated with raising the mass in the column from sea-level to the local height of the surface topography and the change in gravitational potential energy of the mass above the model top (1 Pa or about 0.1 kg m^{-2}) as the height of the top rises and falls. Finally, we add a term, Q_{NUM}, to account for spurious numerical contributions, which we write as a dissipation. In the MERRA data set, these terms were included as part of the output diagnostics. In converting the model to the cube sphere grid, these diagnostics were not developed. More information on the dynamical core tendencies can be found in the MERRA File Specification Document (Lucchesi, 2012).

The vertically integrated physics contribution to the kinetic energy tendency consists of frictional effects due to subgrid-scale motions. It can be separated into contributions due to turbulence, including all boundary layer friction, due to vertical mixing of momentum by the convective parameterization, and due to the friction associated with momentum transport by parameterized gravity waves. Since the GEOS-5 physics does not time split the effects of these three processes, there is some time truncation in the separation and this is stored as a residual.

$$\left[\frac{\partial K}{\partial t}\right]_{PHY} = -\overline{D_{GWD}} - \overline{D_{MST}} - \overline{D_{TRB}} - \overline{\Re_{PHY}}\,,$$

In terms of collection variables, this is:

DKDT_PHY = DKDT_GWD + DKDT_MST + DKDT_TRB + Residual,

where the small spurious contribution, $\overline{\Re_{PHY}}$, from time and space truncation errors, the latter due to the staggering of the winds, were not stored, but can be computed as a residual.

Finally, contributions from the gravity-wave-drag and turbulence parameterizations are further separated into different physical mechanisms:

DKDT_GWD = DKDT_ORO + DKDT_BKG + DKDT_RAY + DKDT_GWDRES

DKDT_TRB = DKDT_INT + DKDT_SRF + DKDT_TOP

Here **DKDT_GWD** is separated into contributions from orographic gravity waves, background gravity waves, Rayleigh friction in the upper atmosphere, and a residual due to the way the terms are implemented. **DKDT_TRB** is separated into contributions from internal diffusion, surface friction, and low-level topographic drag; no residual was stored.

Virtual Enthalpy

We keep a budget of the virtual enthalpy, $H = \overline{c_p T_v}$, where c_p is the heat capacity of dry air at constant pressure and T_v is the virtual temperature. Instantaneous values of this quantity are stored for each grid column in the variable **CPT** in the inst1_2d_int_Nx collection. In the tavg1_2d_int_Nx collection, its total tendency is first separated into contributions from dynamics (**DHDT_DYN)**, physics (**DHDT_PHY)**, and analysis (**DHDT_ANA):**

$$\frac{\partial H}{\partial t} = \left[\frac{\partial H}{\partial t}\right]_{DYN} + \left[\frac{\partial H}{\partial t}\right]_{PHY} + \left[\frac{\partial H}{\partial t}\right]_{ANA}.$$

As with K, the sum of the three contributions obtained from the tavg1_2d_int_Nx collection exactly matches the difference of values in the inst1_2d_int_Nx. For example,

$$\mathbf{CPT_{1:00Z} - CPT_{0:00Z} = 3600.(DHDT\_DYN + DHDT\_PHY + DHDT\_ANA)_{0:30Z}}.$$

The dynamical contribution can be rewritten, separating the conversion term. This leaves:

$$\frac{\partial H}{\partial t} = -\nabla \bullet (\overline{\underset{\rightarrow}{v} c_p T_v}) + \overline{\omega\alpha} + Q_{NUM} + \left[\frac{\partial H}{\partial t}\right]_{PHY} + \left[\frac{\partial H}{\partial t}\right]_{ANA}, \tag{3}$$

where Q_{NUM} is a heating added by the dynamics to conserve total energy in the presence of numerical dissipation–the "energy fixer." These dynamical terms were saved in MERRA, but not derived on MERRA-2's cube sphere grid. See the MERRA File Specification Document for more information (Lucchesi, 2012). Hence, there is a total dynamics term (DHDT_DYN) but not the subterms in eq 3, and global integration of DHDT_DYN is not zero, because the terms other than convergence do not integrate globally to zero. The physics and analysis terms are written out in more detail.

The vertically integrated physics contribution to the H tendency can be separated into contributions due to turbulence, including sensible heat fluxes as well as turbulent friction; contributions due moist processes, including condensation and cumulus friction; and contributions due to the friction associated with momentum transport by parameterized gravity waves. Since the GEOS-5 physics does not time split the effects of these three processes, there is some time truncation in the separation and this is stored as a residual, $\overline{\Re_{PHY}}$.

$$\left[\frac{\partial H}{\partial t}\right]_{PHY} = \overline{Q_{TRB}} + \overline{Q_{MST}} + \overline{Q_{GWD}} + \overline{Q_{RAD}} + \overline{\Re_{PHY}}, \tag{4}$$

and in terms of collection variables:

DHDT_PHY = DHDT_GWD + DHDT_MST –DKDT_MST+ HFLUX - DKDT_TRB + DHDT_RAD + DHDT_RES

The first four quantities on the r.h.s. can be further separated into contributions from more detailed physical processes:

$$\overline{Q_{TRB}} = SH + \overline{D_{TRB}}$$

$$\overline{Q_{GWD}} = \overline{D_{GWD}}$$

$$\overline{Q_{MST}} = -L_v\left[\frac{\partial \overline{q_v}}{\partial t}\right]_{MST} + L_f\left[\frac{\partial \overline{q_i}}{\partial t}\right]_{MST} + L_f P_s + \overline{D_{MST}}$$

$$= -L_v(E_l + E_r - S_s - C_l^{cu} - C_l^{ls} - C_r) - L_s(S_i - C_i^{cu} - C_i^{ls}) + L_f(F_r + F_l + G_s^{coll} - S_s) + \overline{D_{MST}}$$

$\overline{Q_{RAD}} = (SW_T - SW_S) - (OLR + LW_S)$.

Here L_v, L_s, L_f are the latent heats of evaporation, sublimation, and fusion of water, SW_T and SW_S are the net downward fluxes of solar radiation at the top of the atmosphere and at the surface, LW_S is the net downward flux of longwave radiation at the surface, OLR is the outgoing longwave radiation at the top of the atmosphere, and *SH* is the sensible heat flux at the surface. The *D* terms are dissipations, as they appeared in the kinetic energy equation, and the remaining terms are water conversions to precipitation or exchanges between the three phases of suspended atmospheric water, as they appeared in the water budgets.

In terms of collection variables these are:

DHDT_GWD = - DKDT_GWD (4a)

DHDT_MST = $-L_v$ **DQVDT_MST** $- L_f$ **(DQIDT_MST + PRESN)** (4b)

DHDT_RAD = (LWTNET-LWGNET) + (SWNETTOA-SWNETSRF). (4c)

Total Energy

The total energy of the atmospheric column is

$$T = K + H + \phi_S p_S - \phi_T p_T + L_v q_v - L_f q_i$$

Combining equations (1-4):

$$\frac{\partial(K + H + \phi_S p_S - \phi_T p_T)}{\partial t} = -\nabla \bullet (\overline{\underset{\rightarrow}{v}\tfrac{1}{2}|\underset{\rightarrow}{v}|^2} + \overline{\underset{\rightarrow}{v} c_p T_v} + \overline{\underset{\rightarrow}{v}\phi}) + \left[\frac{\partial K}{\partial t} + \frac{\partial H}{\partial t}\right]_{PHY,ANA} + \left[\frac{\partial(\phi_S p_S - \phi_T p_T)}{\partial t}\right]_{ANA} \quad (5)$$

where $\frac{\partial(\phi_S p_S - \phi_T p_T)}{\partial t}$ on the l.h.s. includes the dynamical contribution from (2) as well as the contribution from the physics, which is not separated in the diagnostics. This is a small effect, since in MERRA the physics does not alter the surface pressure. The sum of the physics contributions to (5) can be written:

$$\left[\frac{\partial K}{\partial t} + \frac{\partial H}{\partial t}\right]_{PHY} = (SW_T - SW_S) - (OLR + LW_S) - L_v\left[\frac{\partial \overline{q_v}}{\partial t}\right]_{PHY} - L_f\left[\frac{\partial \overline{q_i}}{\partial t}\right]_{PHY} + SH + \overline{\Re_{PHY}} \quad (6)$$

From the atmospheric water vapor and ice budgets we have

$$\frac{\partial(L_v \overline{q_v} - L_f \overline{q_i})}{\partial t} = -\nabla \bullet (L_v \overline{\underset{\rightarrow}{v} q_v} - L_f \overline{\underset{\rightarrow}{v} q_i}) + L_v\left[\frac{\partial \overline{q_v}}{\partial t}\right]_{PHY,ANA} - L_f\left[\frac{\partial \overline{q_i}}{\partial t}\right]_{PHY,ANA},$$

Where the physics contributions can be written

$$\left[L_v \frac{\partial \overline{q_v}}{\partial t} - L_f \frac{\partial \overline{q_i}}{\partial t}\right]_{PHY} = -L_v(C_r + C_l - E_l - S_s - E_r - E) - L_s(C_i - S_i) - L_f(F_l - G_s^{sedm})$$

$$+ L_v\left[\frac{\partial \overline{q_v}}{\partial t}\right]_{CHM} + L_v\left[\frac{\partial \overline{q_v}}{\partial t}\right]_{FIL} - L_f\left[\frac{\partial \overline{q_i}}{\partial t}\right]_{FIL} \tag{7}$$

Now adding (6) and (7),

$$\left[\frac{\partial T}{\partial t}\right]_{PHY} = (SW_T - SW_S) - (OLR + LW_S) + SH + L_v E + L_f(F_r + S_s + G_s^{sedm} + G_s^{coll})$$

$$+ L_v\left[\frac{\partial \overline{q_v}}{\partial t}\right]_{CHM} + L_v\left[\frac{\partial \overline{q_v}}{\partial t}\right]_{FIL} - L_f\left[\frac{\partial \overline{q_i}}{\partial t}\right]_{FIL}$$

Potential Temperature

The model's dynamics uses virtual potential temperature, θ_v, as the prognostic variable in its thermodynamic equation, we therefore keep its budget. First, we separate its local vertically integrated tendency into contributions from the dynamics, physics, and analysis:

$$\frac{\partial \overline{\theta}_v}{\partial t} = \left[\frac{\partial \overline{\theta_v}}{\partial t}\right]_{DYN} + \left[\frac{\partial \overline{\theta_v}}{\partial t}\right]_{PHY} + \left[\frac{\partial \overline{\theta_v}}{\partial t}\right]_{ANA}$$

The sum of the three contributions obtained from the tavg1_2d_int_Nx collection exactly matches the difference of values in the inst1_2d_int_Nx. For example, the collection-variable equation

$$\mathbf{THV_{1:00Z} - THV_{0:00Z} = 3600.\,(DTHDT\_DYN + DTHDT\_PHY + DTHDT\_ANA)_{0:30Z}}$$

is satisfied within round-off.

Since virtual potential temperature is the prognostic variable used by the dynamical core, it is within round-off while in vertically Lagrangian mode. Both horizontal and vertical advection (i.e., the vertical remapping from the Lagrangian vertical coordinate to hybrid sigma-p) result in diabatic contributions; these are assumed to conserve total energy, but of course, will not conserve θ_v. The total dynamics contribution includes these diabatic tendencies, in addition to the vertically integrated convergence of virtual potential temperature.

$$\left[\frac{\partial \overline{\theta}_v}{\partial t}\right]_{DYN} = -\nabla \bullet (\overline{\underset{\rightarrow}{v}\,\theta_v}) + \left[\frac{\partial \overline{\theta_v}}{\partial t}\right]_{V} + \left[\frac{\partial \overline{\theta_v}}{\partial t}\right]_{H}$$

No further decomposition is done for this budget

Atmospheric Ozone

The model uses odd oxygen mixing ratio, q_{O_x}, as its prognostic variable. Its vertically integrated tendency is given by:

$$\frac{\partial \overline{q_{O_x}}}{\partial t} = -\nabla \bullet (\overline{\underset{\rightarrow}{v}\, q_{O_x}}) + \left[\frac{\partial \overline{q_{O_x}}}{\partial t}\right]_{PHY} + \left[\frac{\partial \overline{q_{O_x}}}{\partial t}\right]_{ANA}$$

or

DOXDT = DOXDT_DYN + DOXDT_PHY + DOXDT_ANA.

The dynamics contribution is simply the vertically integrated convergence. The physics contributions result from parameterized production and loss terms, mostly in the stratosphere. In MERRA, ozone is analyzed and so q_{O_x} can change due to ozone increments or due to increments in atmospheric dry mass. We report only the total analysis contribution. In order to compare the tendencies with the total tendency from the states, a conversion factor of 1.65 mol/mol must be applied to the tendencies.

Land Budgets

Complete budgets for total land water storage and total land energy storage are accessible in the tavg1_2d_int_Nx collection at the full resolution. More detailed partitioning of budget terms can be achieved from quantities in the tavg1_2d_flx_Nx and tavg1_2d_lnd_Nx collections, but these are not saved at the full precision.

Total Land Water Budget

The land surface water balance equation can be written

$$\frac{\partial W}{\partial t} = P_l + P_s - E_L - R_L + \Re_W$$

where W is the total water held in all land surface reservoirs (comprising the soil, the interception reservoir, and the snowpack), P_l and P_s are the liquid rain and "snowfall" rates, respectively, E_L is the total evapotranspiration rate, R_L is the total runoff–surface (or overland) plus baseflow, and $\Re_W$ is a spurious water source. The corresponding collection-variable equation, using quantities stored in tavg1_2d_int_Nx and tavg1_2d_lnd_Nx is

WCHANGE = PRECTOTLAND – EVLAND – RUNOFF – BASEFLOW + SPWATR.

See Section 6 for variable definitions. Note that all of these quantities are values per unit land area, in kg m^{-2} s^{-1} – i.e., not weighted by fractional land area of the grid cell and excluding any contributions from lake, land ice, or ocean tiles. Note also that LND variables **WCHANGE, PRECTOTLAND, EVLAND, RUNOFF, BASEFLOW** and **SPWATR** are defined only at grid cells for which the land fraction is non-zero and are set to the undefined value elsewhere. Also, while the atmospheric parameterizations produce precipitation (**PRECTOT**), the forcing for the land is in the variable **PRECTOTCORR**, the observation driven precipitation field. See Reichle and Liu (2014) for information on **PRECTOTCORR**.

In the tavg1_2d_lnd_Nx collections, the evapotranspiration is separated into components according to its sources as follows:

$$E_L = E_{tr} + E_{bs} + E_{int} + E_{snow} \ ,$$

where E_{tr} is the transpiration rate, E_{bs} is the evaporation from bare soil surfaces, E_{int} is the evaporation from the land's interception reservoir (e.g., water droplets sitting on leaves after a rainstorm), and E_{snow} is the water that sublimates from the snowpack. The corresponding collection-variable equation is

$$\textbf{EVLAND} = \frac{1}{L_v}(\textbf{EVPTRNS} + \textbf{EVPSOIL} + \textbf{EVPINTR}) + \frac{1}{L_s}\textbf{EVPSBLN}$$

where L_v and L_s are the latent heat of vaporization and the latent heat of sublimation, respectively. The MERRA-2 system u uses L_v=2.4665e6 J kg^{-1} (at 15°C) and L_s=2.8002e6 J kg^{-1}.

Total Land Energy Budget

The balance equation for total land surface energy can be written:

$$\frac{\partial \varepsilon}{\partial t} = SW_L + LW_L - SH_L - L_v E_L - L_f \Delta SWE + \Re_L \ ,$$

where ε is the total heat content (in the soil, canopy, and snowpack) relative to liquid water. SW_L is the net shortwave radiation, LW_L is the net longwave radiation, L_v is the latent heat of vaporization (from liquid), E_L is the total evaporation from the land surface, SH_L is the sensible heat flux from the land surface, L_f is the latent heat of fusion, and ΔSWE is the change in the snow water equivalent (through addition of frozen precipitation falling on the surface or removal of snow through melt or sublimation). The term $L_f \ \Delta SWE$ therefore accounts for the snowmelt energy and the added energy needed to evaporate from solid rather than liquid water. The spurious snow energy source $\Re_L$ is explained below.

In terms of "lnd" collection variables the energy budget is:

ECHANGE = SWLAND + LWLAND – SHLAND – L_v **EVLAND**

– L_f**PRECSNOLAND – SPLAND – SPSNOW.**

All of these quantities are computed over land only and are *not* weighted by fractional land area. SPLAND, in analogy to SPWATR, is associated with the coupled land-atmosphere interface in MERRA-2. The term SPSNOW contains "spurious" snow-related energy sources and sinks associated with several small accounting inconsistencies across the coupled models. When, for example, the same amount of snow falls at -20°C in one region and at 0°C in a second region, more energy is needed in the first region to melt the snow, because in the first region, energy is needed first to warm the snow up to 0°C. The atmospheric model does not distinguish between the energy content of snow falling at -20°C and that falling at 0°C, whereas the land model does account for this energy difference. To rectify this inconsistency between the land and atmosphere models, the “negative energy” of the colder snow (i.e., the energy deficit relative to 0°C snow) is “invented” and added to the snow’s internal energy as soon as it hits the surface. It is therefore implicitly included in **ECHANGE**.

References

da Silva, A. M., C. A. Randles, V. Buchard, A. Darmenov, P. R. Colarco, and R. Govindaraju, 2015. File Specification for the MERRA Aerosol Reanalysis (MERRAero). *GMAO Office Note No. 7* (available from http://gmao.gsfc.nasa.gov/pubs/office_notes).

Eaton, B. and co-authors, 2011: NetCDF Climate and Forecast (CF) Metadata Conventions Version 1.6. December 2011. Available at http://cfconventions.org/latest.html.

Molod, A., L. Takacs, M. Suarez, J. Bacmeister, I.-S. Song, and A. Eichmann, 2012. The GEOS-5 Atmospheric General Circulation Model: Mean Climate and Development from MERRA to Fortuna. *NASA Technical Report Series on Global Modeling and Data Assimilation, NASA TM—2012*$^{-1}$*04606*, Vol. **28**, 117 pp.

Molod, A., Takacs, L., Suarez, M., and Bacmeister, J., 2014: Development of the GEOS-5 atmospheric general circulation model: evolution from MERRA to MERRA-2, Geosci. Model Dev. Discuss., 7, 7575-7617, doi:10.5194/gmdd-7-7575-2014.

NOAA, 1995: Conventions for the Standardization of NetCDF Files (COARDS). http://ferret.wrc.noaa.gov/noaa_coop/coop_cdf_profile.html

Reichle, R. H., 2012: The MERRA-Land Data Product, version 1.1. GMAO Office Note No. 3, NASA Global Modeling and Assimilation Office, Goddard Space Flight Center, Greenbelt, MD, USA, 38pp (available from http://gmao.gsfc.nasa.gov/pubs/office_notes).

Reichle, R. H., and Q. Liu, 2014. Observation-Corrected Precipitation Estimates in GEOS-5**.** *NASA/TM–2014*$^{-1}$*04606*, Vol. **35**. http://gmao.gsfc.nasa.gov/pubs/tm/docs/Reichle734.pdf

Reichle, R. H., R. D. Koster, G. J. M. De Lannoy, B. A. Forman, Q. Liu, S. P. P. Mahanama, and A. Toure, 2011: Assessment and enhancement of MERRA land surface hydrology estimates. *J. Climate,* **24**, 6322-6338, doi:10.1175/JCLI-D^{-1}0-05033.1.

Rienecker and Coauthors, 2011: MERRA - NASA's Modern-Era Retrospective Analysis for Research and Applications. *J. Climate,* **24**, 3624-3648, doi:10.1175/JCLI-D^{-1}1-00015.1.

Takacs, L. L., M. Suarez, and R. Todling, 2015. Maintaining Atmospheric Mass and Water Balance Within Reanalysis. *NASA/TM–2014*$^{-1}$*04606*, Vol. **37.** http://gmao.gsfc.nasa.gov/pubs/docs/Takacs737.pdf

Wu, W.-S., R.J. Purser and D.F. Parrish, 2002: Three-dimensional variational analysis with spatially inhomogeneous covariances. *Mon. Wea. Rev.*, **130**, 2905-2916.

Web Resources

GMAO web site: http://gmao.gsfc.nasa.gov/

CF Standard Description: http://cf-pcmdi.llnl.gov/

GEOS-5 Variable Definition Glossary:
http://gmao.gsfc.nasa.gov/products/documents/GEOS5_Glossary_11_01_2011.pdf